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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1960 THANKSGIVING MEETING

AT THE

UNIVERSITY OF CHICAGO, CHICAGO, ILLINOIS

November 25–26, 1960

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November 25, 1960 Series II, Vol. 5, No. 6

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1960 Thanksgiving Meeting at the University of Chicago, November 25–26, 1960

THE Thanksgiving Meeting again returns to the University of Chicago for 1960. The University of Chicago has often been host for the Thanksgiving Meeting. It is fortunate that there are three separate divisions of the University of Chicago which can act as our hosts: The Department of Physics; The Institute for the Study of Metals; and the Enrico Fermi Institute for Nuclear Studies. This time our host is the Enrico Fermi Institute for Nuclear Studies. The Director of the Institute of Nuclear Studies, H. L. Anderson, is the Chairman of our local committee. His Administrative Assistant, Frank R. Borchert, has undertaken much of the work for arranging this meeting of the Society.

The dates of our convention are Friday and Saturday, November 25 and 26.

The Hotel Windermere, 1642 East 56th Street, Chicago 37, Illinois, again has accepted the responsibility of housing those of our members who apply up to the moment when it is booked fully and of finding accommodations in other hotels of the region for those who write later. In writing to the Windermere, mention that you are coming to the meeting of The American Physical Society.

Though Chicago is the usual theater of our Thanksgiving meetings, some people may be unfamiliar with the Chicago area. Advice about the geography of the Chicago area has not appeared since the Bulletin of the Chicago meeting in March, 1958, so it is worth repeating. The University is about seven miles south of the "Loop" or downtown business district of Chicago. There are no hotels within a half-mile of the University; the nearest group of hotels, of which the Windermere is one, lies three-quarters of a mile or thereabouts to the east and northeast. The only good way to go from the Loop in Chicago to the University is to take a suburban train of the Illinois Central Railroad from Michigan Avenue at Randolph Street or at Van Buren Street, and get off at the station marked "55th-56th-57th Street," which is adjacent to the Windermere. At the 56th Street exit from this station there is a taxi stand to the east and a bus stop to the west. Be sure to ask the bus conductor whether he goes to Ellis Avenue and 55th Street; or one may get to the Research Institute Building at 5630 Ellis Avenue by walking along 56th Street a little over a half a mile westward and turning left into Ellis Avenue. People coming to Chicago by train should detrain at Englewood, if they come by the Pennsylvania; at Englewood or Woodlawn, depending on which train they take, if they are to come by the New York Central; at Woodlawn if they come by the Illinois Central; and at the downtown termini if they come by other railroads. Note that Chicago taxicabs make extra charges for extra passengers.

Those arriving in Chicago by air should take note of the fact that there are two airports in Chicago, Midway and O'Hare. The quickest way to get from Midway airport to the University of Chicago is to take a taxi. The cost should be about $3.00. If you go by airport coach you will pay $1.45 to get to the Loop and then will have the problem of getting from the Loop to the University. If you arrive at O'Hare field where all of the Jets arrive, the quickest and most interesting way to get from the airport to the University is to take the Helicopter service from O'Hare to Meigs field near the loop at a cost of $6.00, and then take a taxi which should cost about $2.50. The regular airport bus from O'Hare field to the Loop takes a little over one hour and costs $2.25. A map of the University of Chicago area appears on page 485 of this Bulletin.

The **registration desk** will be situated on the second floor of Eckhart Hall. Members and guests alike must register and pay the modest registration fee of one dollar. **Banquet tickets** will be sold at the registration desk. Announcements of **post-deadline papers,** if any, will be made on blackboards adjacent to the desk. Notice of messages for members may be handed in only by people who have

paid the registration fee, and such notices also will appear on these blackboards.

Our **Division of Solid State Physics** has arranged one session of invited papers which will take place on Friday morning in Mandel Hall. The invited speakers for this session of the DSSP are G. Burns, D. Lazarus, P. Duwez, and J. J. Loferski.

Five Symposia have been arranged for this meeting. The topics for the Symposia are: Meson Physics; High-Energy Physics; Cosmic Rays; Helium-3; and Mössbauer Effect. The Deputy Secretary wishes to express his gratitude to Professor H. L. Anderson for his advice and help in arranging these Symposia.

Invited papers apart from the Symposia are sparse, but four have been included in the program at appropriate points in contributed paper sessions. These will be given by V. Jaccarino, S. E. Darden, L. W. Jones, and S. Raboy.

One hundred and sixty-nine **contributed papers** are distributed among sixteen sessions. This is slightly larger than the number of contributed papers (151) for the Thanksgiving meeting at the Case Institute of Technology in Cleveland last year and is about the same as the last three Chicago meetings: 160, 175, 183. The Thanksgiving meeting has not shown the population explosion that other recent meetings of our Society have shown. We cannot explain this constancy in the number of papers contributed to the Thanksgiving meeting by supposing that physics in the midwest has not grown at the same rate as physics in the rest of the country. Contributions from midwestern institutions to other meetings of the Society have increased significantly. This may mean that physicists would rather travel to one of the coasts to give a paper rather than give it in the midwest.

The **banquet of the Society** will be held on Friday, November 25, at 6:30 p.m. in the Quadrangle Club, 1155 East 57th Street, at the corner of University Avenue. The after-dinner speaker will be announced. Tickets at $4.50 will be on sale at the registration desk, and a form for advance reservations is printed on page 483 of this Bulletin. You are very specially asked to make use of this form, for at this meeting we face the "guarantee hazard" to an aggravated degree. This banquet always presents us with a special problem owing to the ineluctable fact that it must be held on the first day of the meeting. The Society must make a guarantee to the Quadrangle Club even before the meeting begins. Hotels can often adapt themselves to the number of ticket buyers even a few hours before the dinner, but the situation of a club is different, and the Quadrangle Club requires a guaranteed estimate several days before the meeting begins. If we set the guarantee too low, some people will be frustrated by finding that there are no tickets left when they come to buy, but if we set it too high the Society loses money. We are willing to risk some loss for the sake of this, the one unifying feature of the meeting, the only one which all members can attend because there is no simultaneous session to divide them. However, we are afraid to risk too much. We implore the members to fill out and mail the form to be found on the lower half of page 483. Those who pay by checks mailed with the form, and received not later than **November 22,** will find their tickets waiting for them at the desk. Those who do not fill out the form are asked to buy tickets as early as possible on Friday. Cocktails may be purchased in the library of the Quadrangle Club from 5 p.m. on.

The **Council of The American Physical Society** will meet at 10:00 a.m. on Friday in Room 180 of the Research Institute building, 5630 South Ellis Avenue.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance will be considered for admission to the special supplementary program if the abstracts are received at the office of the Society not later than Friday, November 17. The titles of such papers as are accepted will be written on a blackboard near the registration desk, and opportunity for presentation of the papers will be given at the end of Session F or possibly elsewhere in the program.

Prospective meetings and deadlines of the Society will be found listed on page 480 of this Bulletin. Preliminary announcements of the 1961 Annual Meeting at New York; the 1961 March Meeting, which this year will be on the West Coast at Monterey, California; and a preliminary announcement of the meeting of the Division of High-Polymer Physics will be found on page 439.

Make a habit of reading the instructions for the preparation of abstracts, which appear in all issues of the Bulletin and in this one are to be found on page 481. From time to time they become more stringent, for their purpose is to reduce the waste of labor and loss of time spent in editing (i.e., getting ready for the press) abstracts that are badly prepared. Indeed, some of the advice that has been repeatedly given for years is not universally heeded; we are still getting occasional abstracts that are single spaced, offered only as carbon copies, paragraphed, or longer than is allowed. We are on the verge of rejecting all abstracts that do not conform to instructions because of the recent explosion of the number of abstracts submitted for meetings.

A couple of years ago, when it was usual for nearly half of the abstracts to arrive on deadline day, we

printed a warning that it is dangerous to mail abstracts even from points east of the Mississippi less than two days in advance, and still more time should be allowed for those mailed further west. The warning seemed to have had some effect, for the "peak day" for receipt of abstracts moved back from deadline day to the day before. This effect seems to have worn off, since 135 abstracts for this meeting arrived on deadline day. Evidently we have measured some sort of relaxation time so this warning is reiterated.

Errata pertaining to abstracts in this Bulletin will be published in a later issue of this Bulletin if received not later than Monday, November 28, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Write out the corrections in the form (instead of . . . read . . . .) Do not add anything. The privilege of inserting errata is not accorded to enable people to publish additional data or to restore material cut out because the abstract was too long.

W. W. HAVENS, JR., *Deputy Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1960 THANKSGIVING MEETING

(Personal names are those of invited speakers, except at the end of lines where they are those of halls.)

Friday Morning

A. DSSP: Burns, Lazarus, Duwez, Loferski. Mandel Hall.
B. Nuclear structure I. Kent 106.
C. Semiconductors. Breasted Hall, The Oriental Institute.
D. Neutrons. Eckhart 133.
E. Hyperfine structure and nuclear paramagnetic resonance. Social Sciences 122.
F. Plasma physics; post-deadline papers, if any. Rosenwald 2.

Friday Afternoon

G. Dalitz, Good, Nambu, Sakurai. Mandel Hall.
H. Sessler, Meyer, Wheatley, Edwards. Kent 106.
I. Optical properties of solids. Breasted Hall, The Oriental Institute.
J. Darden; apparatus of nuclear physics. Eckhart 133.
K. Electron paramagnetic resonance. Social Sciences 122.
L. Lattices and structures. Rosenwald 2.

Friday Evening at 6:30

Banquet of The American Physical Society. Quadrangle Club.

Saturday Morning

M. Hanna, Nagle, Wertheim, Frauenfelder. Mandel Hall.
N. Nier, Turkevich, Friedlander, Meyer. Kent 106.
O. Solid-state physics. Breasted Hall, The Oriental Institute.
P. Nuclear structure II. Eckhart 133.
Q. High-energy physics. Social Sciences 122.

Saturday Afternoon

R. Hincks, Sard, Wright, Yodh. Kent 106.
S. Mössbauer effect. Mandel Hall.
T. Jaccarino; Knight shift studies and metals. Breasted Hall, The Oriental Institute.
U. Jones, Raboy; atomic and molecular physics. Eckhart 133.
V. Theoretical physics. Social Sciences 122.

PROGRAMME

FRIDAY MORNING AT 10:00

Mandel Hall

(E. BURSTEIN presiding)

Invited Papers from the DSSP

A1. Nuclear Quadrupole Resonance and Electron Paramagnetic Resonance in Guanidine Aluminum Sulfate Hexahydrate and Isomorphous Compounds. G. BURNS, *IBM Research Laboratories.* (30 min.)

A2. Effect of High Pressure on Diffusion in Solids. D. LAZARUS, *University of Illinois.* (30 min.)

A3. Metastable Structures in Alloys Rapidly Cooled from the Melt. P. DUWEZ, *California Institute of Technology.* (30 min.)

A4. Studies of Radiation Damage and Its Thresholds in Semiconductors by Observations on *p-n* Junctions. J. J. LOFERSKI, *RCA Laboratories.* (30 min.)

FRIDAY MORNING AT 10:00

Kent 106

(S. E. DARDEN presiding)

Nuclear Structure I

B1. Polarization of Neutrons from the $Be^9(p,n)B^9$ Reaction.* C. A. KELSEY,† T. R. DONOGHUE, AND S. E. DARDEN, *University of Notre Dame.*—The polarization P_n of the neutrons from the $Be^9(p,n)B^9$ reaction has been measured for proton energies from 2.29 to 4.34 Mev. Beryllium targets (35 to 120 kev) prepared by evaporation onto tantalum backings were bombarded by a proton beam from the Notre Dame electrostatic accelerator. Neutrons emitted at a laboratory angle of 50° to the proton beam were scattered from various analyzers, and the resulting left-right asymmetry in scattering was used to determine P_n. Lithium, liquid oxygen, and carbon were used as scatterers for proton energies of 2.29, 2.45 to 3.32, and 3.91 to 4.34 Mev, respectively. For bombarding energies below 3.91 Mev, the scattered neutrons were detected by a hydrogen-filled proportional counter. A loaded plastic scintillator was used for proton energies above 3.91 Mev. The detection efficiency for three-body breakup neutrons was minimized by suitable energy discrimination. Left-right asymmetries in the scattering were observed without moving the detector by rotating the neutron spin through 180° with an electromagnet. The results are consistent with a polarization of less than 10% throughout the energy region investigated.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Summer Fellow.

B2. Cross Sections and Angular Distributions of Neutrons from $C^{13}(d,n)N^{14}$ (Ground State, 2.31-, 3.95-, 4.91-, and 5.10-Mev Levels of N^{14}).* F. J. VAUGHN, L. F. CHASE, JR., AND R. G. JOHNSON, *Lockheed Missiles and Space Division Research Laboratory.*—Angular distributions and excitation functions of neutrons from the $C^{13}(d,n)N^{14}$ reaction have been measured for deuteron energies from 1.3 Mev to 3.1 Mev, using a neutron time-of-flight technique. Neutron groups emitted when the N^{14} residual nucleus was left in the ground state and in the first four excited states at 2.31, 3.95, 4.91, and 5.10 Mev were observed. The angular distributions were measured from 0° to 155° from the incident beam direction at energy intervals of 0.1 Mev, while the excitation functions were observed at 20° in steps of 25 kev. A thin target prepared by cracking methyl iodide (enriched to 58% C^{13}) onto a hot tantalum backing was used in the experiment. A good $l_p=0$ stripping pattern was observed throughout the energy interval for the neutron group corresponding to the residual nucleus in the 4.95-Mev level. The neutron angular distributions for N^{14} in the ground state and second excited state showed pronounced peaking in the backward direction, while the neutron group corresponding to the first excited state of N^{14} was generally too weak for accurate analysis.

* Supported by the U. S. Air Force Special Weapons Center.

B3. Scattering of Protons by Carbon.* F. L. BORDELL, G. E. MITCHELL, P. B. WEISS, J. W. NELSON, AND R. H. DAVIS, *Florida State University.*—States in N^{13} have been studied by scattering protons from thin carbon foils (99% C^{12}, 0.2 mg/cm²). In the proton bombarding energy range 5.2 to 11.3 Mev, elastic scattering anomalies have been observed at 5.37, 5.90, 6.6, 7.50, 8.2, 9.15, 10.31, 10.55, and 11.00 Mev. The 6.6-Mev anomaly is several Mev wide and is consistent with a $\frac{3}{2}^+$ assignment for the state in N^{13}. Resonances at 5.37, 5.90, and 6.6 have been reported in the literature, and the anomalies at 7.5, 8.2, 9.15, 10.31, and 10.55 have been observed by Dearnaley and Whitehead.[1] Except for the 6.6-Mev resonance, the resonances have appreciable inelastic widths. Although complicating the elastic scattering analysis, the observation of the angular distribution of the inelastic proton groups assists in removing ambiguities in level assignments. The excitation curve from 10.1 to 11.3 indicates the existence of at least three resonances in that interval. Phase shift analysis is being carried out with the assistance of an IBM 650 computer.

* Supported in part by U. S. Air Force Office of Scientific Research.
[1] G. Dearnaley and A. B. Whitehead, Kingston Conference on Nuclear Structure.

B4. $C^{13}(p,p'\gamma_{4.43})C^{13}$ Excitation Function between 5 and 11 Mev.* H. S. ADAMS, J. A. BECKER, J. D. FOX, N. P. HEYDENBURG, AND G. M. TEMMER, *Florida State University.*—We have extended the excitation function for $C^{13}(p,p'\gamma)C^{13}$ to 11.5-Mev

bombarding energy. We detected the 4.43-Mev gamma ray from the first excited state of C^{12} produced in a thin (0.3 mg/cm²) carbon foil at 90° with a 5-in.×4-in. NaI(Tl) crystal. In addition to the known resonances at 5.36 and 5.89 Mev,[1] we saw a number of resonances corresponding to states in N^{13} of up to 12-Mev excitation. We also observed a smoothly rising yield underlying the resonances, beginning at about 6 Mev. The approximate energies of the observed resonances

TABLE I.

E_{res}(Mev)	Excitation energy of N^{13}(Mev)	Γ_{lab}(kev)
5.36	6.89	140
5.89	7.38	70
7.58	8.94	255
8.18	9.49	38
9.13	10.37	70
10.51	11.64	85
10.74	11.85	140
10.99	12.09	150

are listed in Table I. Measurements of angular distributions of the 4.43-Mev gamma ray are in progress at several energies.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] C. W. Reich, G. C. Phillips, and J. L. Russell, Jr., Phys. Rev. 104, 143 (1956).

B5. Parameters for a Dinucleus Model for Heavy Ion Reactions.* R. H. DAVIS, *Florida State University.*—A dinucleus model has been proposed[1] in which the specifically nuclear part of the potential is the real optical model potential. Analyses of recent Chalk River experiments on the $C^{12}+C^{12}$ system yield assignments of 8^+ and 4^+ for the resonances at 5.65 and 5.98 Mev (c.m.), respectively. While the parameters adopted from Porter's work predict a 4^+ ($N=3$, $L=4$) level near 6 Mev, no 8^+ level lay within 3 Mev. By determining the variation of energy levels with the depth, diffuseness, and radius parameters, the effects of parameter adjustments and the uniqueness of values can be studied. The C+C data can be fitted with a well depth of 48.5 Mev and diffuseness of 0.80 f, the latter being weakly determined. By leaving $V_0=40$ Mev and $\delta=0.574$ f, pairs of $L=4$ and 8 resonances are also fitted for two values of the radius parameter (1.32 and 1.50 f). Experimental assignments for additional levels in the C+C or other systems are needed to remove the ambiguity. Theoretical results will be presented for the C+O, O+O, and N+N systems for several sets of parameters. By adding an imaginary part to the potential well, the reaction cross sections may be parameterized. The formation of dinucleus states is intimately related to the extension of the real potential outside the absorptive region.

* Supported in part by the U. S. Air Force Office of Scientific Research and the Florida State University Research Council.
[1] R. H. Davis, Phys. Rev. Letters 4, 521 (1960).

B6. Elastic Scattering of Alpha Particles by N^{14}.* E. A. SILVERSTEIN, G. HARDIE, L. OPPLIGER, AND S. SALISBURY, *University of Wisconsin.*—The differential cross section for $N^{14}(\alpha,\alpha)N^{14}$ was measured with thin (~2-kev) gas targets in a differentially pumped gas scattering chamber for E_α between 1 and 2.4 Mev. The energy range was surveyed at θ(c.m.) $=169°\ 58'$, and data were taken in the region of resonances at θ(c.m.) $=140°\ 46'$, $125°\ 16'$, $90°$, and $54°\ 44'$. Cross-section anomalies were observed corresponding to previously observed[1] resonances at laboratory resonant energies of 1.52, 1.63, 2.16, 2.35, and 2.37 Mev. By use of the Wigner-Eisenbud one-level formula and folding in of the experimental resolution, the first two levels were found to be formed by $l=1$ alphas, which is consistent with the previous[1] assignments of $J=1^-$ for both. The 2.16-Mev resonance was formed by $l=3$ alphas. The real widths of these three levels are ~200 ev. The 2.35- and 2.37-Mev data confirm Herring's[1] assignments of $l=3$ and $l=0$, respectively, for the alphas forming these resonances. Since the experimental resolution (mainly from straggling and target thickness) was large compared to the real resonance widths, J values could not be assigned.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. 11, 239 (1959).

B7. $O^{16}(He^3,He^3)O^{16}$ and $O^{16}(He^3,He^4)O^{15}$ Cross-Section Measurements.* L. OPPLIGER, E. A. SILVERSTEIN, G. HARDIE, AND S. SALISBURY, *University of Wisconsin.*—The differential cross sections for $O^{16}(He^3,He^3)O^{16}$ and $O^{16}(He^3,He^4)O^{15}$ were measured using a differentially pumped gas scattering chamber. The elastic scattering was measured over a laboratory He^3 range from 1 to 3.1 Mev at θ(c.m.) $=169°$, from 2.05 to 2.7 Mev at θ(c.m.) $=100°$, and from 1.3 to 2.35 Mev at θ(c.m.) $=90°$. In addition, angular distributions were taken at E_{He^3}(lab) $=1.941$ and 2.373 Mev. The excitation function of the alpha particles from the $O^{16}(He^3,He^4)O^{15}$ ground state was measured at θ(c.m.) $=97°$. Resonance structure like that found by Bromley[1] *et al.* was observed in the alpha-particle excitation function. The elastic scattering data in the resonance region shows evidence of destructive interference with Rutherford scattering near θ(c.m.) $=90°$, leading to an even l value assignment to the He^3's forming the compound states in Ne^{19}. The resonance structure has been interpreted[1] as arising from interference between two levels in Ne^{19} of the same parity, with $J=\frac{1}{2}$ and $\frac{5}{2}$. Our data then determine this parity to be even. The back angle elastic scattering cross section starts to rise at $E_{He^3}=2.9$ Mev, indicating the start of another resonance.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] D. A. Bromley, J. A. Kuehner, and E. Almqvist, Nuclear Phys. 13, 1 (1959).

B8. Elastic Scattering of Protons by O^{16}.* S. SALISBURY, G. HARDIE, L. OPPLIGER, AND R. DANGLE, *University of Wisconsin.*—The elastic scattering of protons on O^{16} was investigated in the energy range of 4.40 Mev to 8.70 Mev at the center-of-mass scattering angle of $166°\ 52'$. Data were taken at 2.5-kev intervals with a 3-kev gas target thickness and an energy resolution of several kev. Twenty resonances were found, with half-widths varying from about 5 kev to about 0.5 Mev. The absolute cross sections are expected to be given within 1%. Higher energy cross-section measurements are in progress.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

B9. Formation of Na^{22} and Na^{24} from Al with 25- to 40-Mev Alpha Particles.* NORBERT T. PORILE, *Brookhaven National Laboratory.*—Excitation functions have been measured for the formation of Na^{22} and Na^{24} from aluminum with 25- to 40-Mev alpha particles. The cross sections for both reactions are less than 0.001 mb at a bombarding energy of 31 Mev. Above this energy the cross sections for the formation of both products increase rapidly and at 40 Mev attain values of 4.3±0.4 mb and 0.20±0.03 mb for Na^{22} and Na^{24}, respectively. The projected ranges of the recoils along the beam direction have been measured in aluminum. The values for both Na^{22} and Na^{24}, as given by $R=F\times W$, where F is the fraction of the activity recoiling out of the target and W is the target thickness, are 0.8±0.1 mg/cm² for 39- to 40-Mev alpha particles. Interpolation between available range-energy data gives kinetic energies of approximately 3–4 Mev for the recoils. The kinetic energy of the recoils expected for compound nucleus formation is 4 Mev while that expected for direct interaction processes is much smaller. The results thus indicate that com-

pound nucleus formation is an important mechanism for these reactions.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

B10. $Si^{28}(p,p'\gamma)$ Angular Correlations.* H. F. BOWSHER,† G. F. DELL, AND H. J. HAUSMAN, *The Ohio State University.*—Angular correlations have been measured between protons scattered inelastically from a Si^{28} target and the decay gamma rays from the 1.78-Mev first excited state of the target nuclei. The incident proton bombarding energy was varied between 5.8 Mev and 7.0 Mev. The angular correlation experiments were performed for proton detector angles of 37°, 60°, 90°, and 120°. The measured angular correlation functions are all of the form $A+B\sin^2 2(\theta-\theta_0)$, where θ_0 is the axis of symmetry. When the incident proton beam energy was 7.0 Mev, the symmetry direction was found to be 90° (c.m.) independent of the proton detector angle. These results agree with the predictions of a compound-nucleus theory. This suggests the existence of a strong compound-nuclear resonance in P^{29} at an excitation energy of 9.6 Mev. For lower proton beam energies, the symmetry direction θ_0 shifts with a change in the proton detector angle or a change in the proton beam energy. These results are consistent with a direct-reaction mechanism.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Department of Physics, The University of Tennessee.

B11. Evidence for the S^{30} Isotope.* R. G. JOHNSON, L. F. CHASE, AND W. L. IMHOF, *Lockheed Missiles and Space Division Research Laboratory.*—The bombardment of natural silicon targets with 3-Mev He^3 ions produced a positron activity with 1.5±0.1-sec half-life in coincidence with a 676±8-kev gamma ray. The beta rays in coincidence with 676-kev gamma rays were measured with a beta-gamma coincidence scintillation spectrometer, and the end point of the beta spectrum was found to be 4.22±0.15 Mev. Since the P^{30} ground state and first excited state at 686±5 kev have been measured previously as 1^+ and 0^+, respectively, and since S^{30}, being even-even, is expected to have a 0^+ ground state, the decay of S^{30} would be expected to decay primarily via the super-allowed transition to the 686-kev state for decay energies near 5 Mev. The constancy of the yield of the 676-kev gamma ray from the bombardment of five different high-purity silicon targets indicated that the activity could not be reasonably assigned to target impurities. At a bombarding energy of 3 Mev, all He^3 reactions with the silicon isotopes except the $Si^{28}(He^3,n)S^{30}$ reaction produce activities with known half-lives different from 1.5 sec or produce stable isotopes. These and other more detailed considerations lead to the assignment of the observed 1.5-sec activity to S^{30}.

* Supported jointly by the Lockheed General Research Program and the U. S. Atomic Energy Commission.

B12. Aluminum (p,γ) Resonance Yields with Hydrogen Molecular Ions.* P. F. DAHL, D. G. COSTELLO, AND W. L. WALTERS, *University of Wisconsin.*—Thick target gamma-ray yield curves from resonances in the $Al^{27}(p,\gamma)Si^{28}$ reaction were studied with H_1^+, H_2^+, and H_3^+ ions, under a variety of conditions. Resonance yield curves from molecular ions are very broad, asymmetric, and fairly complicated in shape, giving an apparent downward shift in resonance energy by approximately 0.05%. A broad intermediate step is observed in the thick target yield for a beam energy resolution of 0.1% and a peak centered above the resonance for higher resolution. Diatomic ion effects are explained and yield curves accurately fitted by taking into account the Coulomb energy of the two protons from the ion in the center-of-mass system, assuming the electron is torn away as the target is struck. A proton oriented forward in the ion receives an impulse in the forward direction and the trailing proton a retarding impulse. Preliminary calculations indicate that accurate thin target data, in which Coulomb effects are minimized, may throw light on the internal vibrational motion of the protons in the H_2^+ ion.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

FRIDAY MORNING AT 10:00

Breasted Hall, The Oriental Institute

(L. R. WEISBERG presiding)

Semiconductors

C1. Excess and Hump Current in Esaki Diodes.* R. S. CLAASSEN, *Sandia Corporation.*—An energy dissipating tunnel transition from a localized defect level in the transition region is proposed to explain the excess current I_x in Esaki diodes.[1] The relation to bias voltage V_F is

$$I_x = \text{const}\exp\left[-\frac{4}{3}\frac{(2em_e)^{\frac{1}{2}}}{\hbar}W_0\left(\frac{\epsilon-\epsilon_d-\zeta_V}{eV}\right)^{\frac{1}{2}}(V-V_F)\right], \quad (1)$$

where W_0 is the junction width at unit voltage ϵ the energy gap, ϵ_d the level of the defect below the conduction band, ζ_V the Fermi level in the valence band, and V_D the diffusion voltage. The hump current may be expiained in terms of equi-energy defect-to-band tunneling analogous to the band-to-band tunneling.[1] Electron irradiation (2 Mev) has produced large humps in germanium diodes and two distinct humps in silicon and gallium arsenide diodes indicating defect levels in fair agreement with those observed by other techniques. The appearance of the humps is accompanied by two straight-line portions of the ln I_x vs V_F curve. For gallium arsenide the relation of the slopes is given by Eq. (1), using the two values of ϵ_d determined by hump location. This model differs from Logan and Chynoweth[2] in that discrete defect levels account for I_x.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] L. Esaki, *Solid State Physics in Electronics and Telecommunications* (Academic Press, Inc., New York, 1960), Vol. I, p. 514.
[2] R. A. Logan and A. G. Chynoweth, Bull. Am. Phys. Soc. Ser. II, 5, 375 (1960).

C2. Tunneling from Trap States in Esaki Diodes. P. J. PRICE, *IBM, Watson Laboratory.*—It has been suggested[1] that excess current in Esaki diodes entails a tunneling transition between a localized trap state and the conduction (or valence) band. The probability per unit time of tunneling from a trap has been calculated. It is approximately

$$\frac{\pi^2 m^*}{h^3 d}|W|^2 e^{-2\theta},$$

where W is the matrix element, between the band-edge Bloch

state (normalized in unit volume) and the trap state, of the local trap potential in excess of the crystal potential; d is the length of the "forbidden path" terminating at the trap; and θ is the usual integral[3] appropriate to this path. The expected dependence of excess current on voltage is different for this mechanism, for tunneling with radiation, and for the Shockley-Read process with the transitions to and from the "forbidden tails" of band states.

[1] T. Yajima and L. Esaki, J. Phys. Soc. Japan 13, 1281 (1958).
[2] P. J. Price and J. M. Radcliffe, IBM J. 3, 364 (1959).

C3. Effects of Magnetic Fields on Esaki Tunneling. R. R. HAERING AND E. N. ADAMS, *IBM Research Center.*—It has been observed by Esaki[1] and by Calawa, Rediker, Lax, and McWhorter[2] that the tunneling current of an Esaki diode may be considerably reduced by a sufficiently strong magnetic field in either transverse or longitudinal orientation. Calawa[2] and Price[3] have given an expression for the current reduction in the longitudinal orientation. We shall give a brief qualitative account of the physical mechanism of current reduction in strong fields and report the result of a calculation of the current reduction for the transverse orientation. The situations in the two orientations are somewhat different. In the longitudinal case, the tunneling must be predominately from the states of zero point motion about the field, since these have the maximum amount of energy available for tunneling. In the transverse case, the quantized motion about the field must provide the kinetic energy for tunneling, and hence tunneling is predominately from states of the largest possible quantum number; but because of the circling motion of the carrier only a part of the transverse energy is available for tunneling. The critical energy is not the zero point energy but a quantity which depends on the width of the junction and on the reduced carrier mass. Expressions will be given for the magnitude of the current reduction for either orientation, in the approximation in which the shift of the Fermi level is ignored.

[1] L. Esaki (private communication).
[2] A. R. Calawa, R. H. Rediker, B. Lax, and A. L. McWhorter, Phys. Rev. Letters 5, 55 (1960).
[3] P. J. Price (private communication).

C4. Energy-Band Structure of Solids from a Perturbation on the "Empty Lattice."*† FRANCO BASSANI, *Argonne National Laboratory,* AND VITTORIO CELLI, *University of Illinois.*—A simple perturbation approach is developed to obtain the energy-band structure of solids. The unperturbed Hamiltonian consists of the kinetic part and of a uniform potential; the perturbing operator is the crystal potential plus a term which originates from the requirement that valence and conduction states be orthogonal to the inner states. This amounts to an approximation to the O.P.W. method. Reasons are given for the validity of such a simple scheme, and applications are made to the case of the diamond lattice and of the zinc blend lattice. It is shown how features of the energy-band structure depend on the symmetry of the lattice, on the lattice parameter, and on the "core states" of the atomic components. Numerical results obtained for diamond, silicon, and BN are in agreement with recent calculations. An energy-band structure consistent with experimental information is obtained for Ge and GaAs by fixing the values of a few parameters.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
† Supported in part by a U. S. Air Force Research and Development Command contract.

C5. Behavior of Carbon in GaAs.* B. GOLDSTEIN AND L. R. WEISBERG, *RCA Laboratories.*—A crystal of GaAs has been grown by the horizontal Bridgman technique in a quartz boat coated with a radioactive carbon film. The film was prepared by cracking acetone containing C^{14} labeled methyl groups. Sections were removed along the crystal for both autoradiographs and absolute radioactive counting. The carbon was found to be homogeneously distributed throughout the bulk in the range of 3 to 8×10^{16} cm^{-3}. No segregation was observed at the grain boundaries; however, occluded carbon was observed at the surface of the crystal. The effective distribution coefficient of the carbon is found to be about 0.8. Samples were also removed for emission spectrographic analysis and for measurements of carrier concentration and Hall mobility. It was found that silicon was the major detectable impurity in the crystal, with a concentration varying from the front to the tail from 1 to 30 ppm atomic. The electron concentration varied from 3×10^{16} to 1.5×10^{18} cm^{-3}, and the mobility was below 3500 cm^{2}v^{-1} sec^{-1}. This low mobility is characteristic of crystals grown in contact with carbon.

* Sponsored by a contract of the Electronics Research Directorate of the U. S. Air Force Research Division—Air Research and Development Command.

C6. Measurements on GaAs-GaP Alloys.* H. FLICKER AND P. G. HERKART, *RCA Laboratories.*—A series of $GaAs_{1-X}P_X$ alloys have been successfully prepared $0\leq X\leq 1$, despite the previously reported difficulties[1] in the range $0<X<0.2$. Measurements of lattice constant and chemical composition have been carried out by x ray and spectrochemical analysis in the range of $0\leq X\leq 0.5$. The results indicate that Vegard's law is obeyed. The optical band gap has been measured and is in agreement with previous results.[1] Hall measurements on a sample of $X=0.15$ having a 1.6-ev band gap showed an electron Hall mobility of 1700 cm^2 v^{-1} sec^{-1}. In the range $0\leq X\leq 0.5$ the absorption curve is similar to that observed in GaAs, and in samples of $X\geq 0.7$ the absorption curve is similar to that observed in GaP. This would indicate that the absorption process changes from a direct transition, as in GaAs, to an indirect transition as in GaP[2].

* Sponsored by the Electronics Research Directorate of the U. S. Air Force Research Division.
[1] H. Welker and H. Weiss, *Solid State Physics,* edited by F. Seitz and D. Turnbull, Vol. 3, p. 53.
[2] E. E. Loebner and E. W. Poor, Jr., Phys. Rev. Letters 3, 23 (1959).

C7. Temperature Dependence of the Resistivity, Hall Coefficient, and Thermal Power in TiO_3. JACK YAHIA AND H. P. R. FREDERIKSE, *National Bureau of Standards.*—The resistivity ρ, Hall coefficient R_H, and thermoelectric power Q of nonstoichiometric titanium sesquioxide (1 atomic percent excess oxygen) have been measured from 55°K to high temperatures. Ti_2O_3 shows a transition point at 475°K, as evidenced by the sharply dropping resistivity and thermoelectric power. (The Hall coefficient was too small to measure above 400°K.) Above this point there are indications of metallic behavior (i.e., negative Q, positive temperature coefficient for ρ), and below this point the behavior is that of a p-type semiconductor. R_H and ρ increase at a decreasing rate as the temperature is lowered, and in some cases the samples show an approximately constant R_H and ρ below 100°K, suggesting a degenerate hole gas. The temperature dependence of the mobility suggests scattering by polar modes and by impurities at high and at low temperatures, respectively. The mobility is found to be ~3 cm^2/v-sec at 300°K. The thermoelectric power increases as the temperature decreases and goes through a maximum at about 100°K, decreasing again at lower temperatures. A simple analysis involving R_H, ρ, and Q yields an effective mass $\sim 5m_0$ (where m_0 is the electronic mass), and the same result is obtained from the mobility in the polar scattering range.

C8. "Impurity Species Effect (As, Sb) on the Thermal Conductivity and Thermoelectric Power of Germanium at Low Temperatures." J. F. GOFF AND N. PEARLMAN, *Purdue University.*—At temperatures below that of the thermal conductivity k maximum T_m, Ge single crystals containing between 6×10^{16} and 2×10^{18} cm^{-3} nominally noncompensated Sb impurities show a thermal resistivity w which increases

with impurity concentration and exhibits a T^{-n} dependence where n is approximately 4. Sb doped samples, heavily compensated (80% or more) in the melt with Ga, exhibit a decreased w; and it is possible to correlate $w(T)$ with n_{ss} the exhaustion carrier concentration. Thus w apparently arises from an electron-phonon interaction that is independent of the electron transition probabilities in the impurity band (as indicated by the differing electrical resistivities of the noncompensated and compensated samples at these temperatures). Further, similar Ge samples containing 2×10^{16} to 1×10^{17} nominally noncompensated As impurities per cm^3 show less w per carrier than do the Sb doped ones and exhibit a T^{-3} dependence approximately, while a degenerate As doped sample yields results like the degenerate Sb doped ones. These results will be discussed with respect to the Keyes model of thermal resistance.[1] The thermoelectric power Q of the noncompensated, nondegenerate Sb and As doped samples differ markedly in that Q(Sb) decreases at these low temperatures ($T<T_m$) while Q(As) increases (the degenerate As doped sample behaves similarly to the degenerate Sb ones). If Q is predominantly due to phonon drag, then k and Q have the same relaxation time at these temperatures and $k/Q\propto T^4\mu$ where μ is the electron mobility. In the hopping range (2×10^{16} cm^{-3} impurities), μ is temperature independent and $k/Q\propto T^4$. For this concentration we find T^4 and $T^{3.4}$ for Sb and As impurities, respectively.

[1] R. W. Keyes, Bull. Am. Phys. Soc. Ser. II, 5, 264 (1960).

C9. Susceptibility of Donors in Germanium. D. H. Damon and A. N. Gerritsen, *Purdue University.*—The magnetic susceptibility of several n-type germanium samples has been measured by the Faraday method between 4.2°K and 1.35°K. Sonder and Schweinler[1] have observed that the spin paramagnetism of electrons localized on donors in silicon does not follow the Curie Law at moderate donor concentrations. They have explained this in terms of a hydrogen molecule-like interaction between donors, and they predicted that similar behavior would be observed in n-type germanium with donor concentrations below 5×10^{16} cm^{-3}. The results to be reported concern germanium samples with donor concentrations between 2 and 6×10^{16} cm^{-3}. Both antimony and arsenic doped samples have been measured. Within experimental error these results show that the molecule theory predicts the observed temperature dependence of the donor susceptibility at appropriate donor concentrations. The antimony doped samples exhibit a stronger donor interaction and a larger orbital diamagnetism than the arsenic doped samples, consistent with the hydrogen model. The observed orbital diamagnetism of the localized electrons is smaller than that predicted for isolated donors. Again, this might be explained in terms of a hydrogen molecule-like interaction between donors.

[1] E. Sonder and H. C. Schweinler, Phys. Rev. 117, 1216 (1960).

C10. High-Field Transverse Magnetoresistance of n-Type Germanium.* T. J. Diesel and W. F. Love, *University of Colorado.*—Measurements have been made of the transverse magneto resistance of high-purity, single-crystal, n-type germanium, in pulsed magnetic fields up to 194 kgauss, in the temperature range from 11°K to 78°K. "Hot electron" effects and nonohmic behavior of the crystal have obscured the results below about 20°K, but in the quantum limit and above, the magneto resistance was found to increase linearly with magnetic field above 40 kgauss. At 23°K and 180 kgauss, the resistance of the crystal was about 19 times its zero field resistance. This resistance ratio has roughly a T^{-1} temperature dependence. The results of these experiments do not agree with theoretical predictions for various scattering mechanisms.[1]

* Supported by the U. S. Army Office of Ordnance Research.
[1] E. N. Adams and T. D. Holstein, J. Phys. Chem. Solids 10, 254–276 (1959).

C11. Energy Loss of Warm Electrons in n-InSb Caused by Piezoelectric Scattering. R. J. Sladek, *Westinghouse Research Laboratories.*—The electron mobility in n-InSb depends on electric field strength F even at quite low fields.[1] To account for the change in mobility at 4.2°K which is proportional to F^2 we have employed a model in which the electrons lose their momentum to ionized impurities but lose their energy to piezoelectrically active acoustic modes. The probabilities of electronic transitions involving such modes have been given by Meijer and Polder.[2] By using these transition probabilities we have derived a theoretical expression for energy loss caused by piezoelectric scattering by employing the method of Greene.[3] This expression will be presented. By use of it theoretical predictions for the field dependence of the mobility have been obtained which agree well with our experimental results on n-InSb samples having between 2.8×10^{14} and 8.7×10^{15} electrons/cc if the piezoelectric constant e_{14} has a value of about 2.6×10^4 (dynes)$^{\frac{1}{2}}$/cm.

[1] R. J. Sladek and F. S. Black, Jr., Bull. Am. Phys. Soc. Ser. II, 3, 378 (1958).
[2] H. J. G. Meijer and D. Polder, Physica 19, 255 (1953).
[3] R. F. Greene, J. Electronics and Control 3, 387 (1957).

C12. $1/f$ Trapping Noise in CdS.* James J. Brophy, *Armour Research Foundation.*—The shape of the high-frequency portion of the current noise spectra observed in lightly doped CdS single crystals under uniform 5200A illumination is characteristic of electron trapping transitions in shallow levels. In many crystals the spectra have a $1/f$ behavior when the quasi fermi level is not located at a discrete trap. The $1/f$ trapping noise spectra observed in one sample at three temperatures and for twenty different positions of the electron quasi fermi level between 0.5 and 0.3 ev below the conduction band can be represented by a single expression of the form $(1/\omega)\tan^{-1}\omega\tau$, where τ is determined by the low-frequency turnover of the $1/f$ noise. From the experimental values of τ in each instance trap depths are calculated which are in good agreement with those determined from the discrete trapping spectra.[1] Since the low-frequency turnovers of the $1/f$ spectra are thus related to the discrete traps, rather than to the position of the electron quasi fermi level directly, it appears that the $1/f$ noise is not associated with a continuous distribution of traps in energy but rather with a dispersion of capture and release times into the discrete traps.

* Supported by the Office of Naval Research.
[1] J. J. Brophy and R. J. Robinson, International Conference on Semiconductor Physics, Prague, September, 1960, Paper V9.

C13. Texture in Evaporated Germanium Films. J. E. Davey and A. J. McAlister, *U. S. Naval Research Laboratory.*—Structure in vacuum evaporated thin germanium film deposited on neutral substrates has been investigated between temperatures characteristic of the amorphous state up to the melting point of germanium. Both hot deposition and annealing have been employed to determine possible structural changes. Deposited hot or annealed films between 375 and 475°C yield the standard crystalline powder pattern in reflection electron diffraction. Depositing hot between 150° and 350°C yields a weak to strong 110 fiber structure depending on the temperature extrema. Films deposited near the lower temperature range of observable 110 structure also yield a 111 orientation in coexistence with the superficial 110. Hot deposition at near 600°C yields the single 111 fiber orientation. Treatment above 650°C results in mild to strong random crystal growth out of the plane of the film; in the vicinity of 800° to 900°C whiskers and facets up to 0.05 mm in extent have been observed.

FRIDAY MORNING AT 10:00

Eckhart 133

(L. BOLLINGER presiding)

Neutrons

D1. Pyrolytic Graphite Cold Neutron Cross Section. J. R. ROESSER* AND R. E. SLOVACEK, *Knolls Atomic Power Laboratory.*†—Attempts have been made to calculate the inelastic scattering of neutrons by graphite.[1] The experimental evidence with which the calculations may be compared is hampered by the anisotropy of the usual polycrystaline samples[2] and the uncertainty as to the effect of small-angle scattering. In the present measurement, the slow chopper technique was used to measure the cross section of pyrolytic graphite for neutron wavelengths between 4.5 and 9 A. In the sample[3] measured, the basal planes of the graphite are very highly ordered parallel to each other throughout the material. This, to a large extent, eliminates the adverse effects noted above. The comparison between the calculated cross section and the experimental data will be discussed. Preliminary results seem to agree with the results obtained by H. Palevsky[4] at Brookhaven using a polycrystaline sample and a different technique.

* Extracted from a thesis submitted in partial fulfillment of the requirements for a Master's Degree in Physics at Rensselaer Polytechnic Institute.
† Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] P. G. Khubchandani, L. S. Kothari, and K. S. Singwi, Phys. Rev. 110, 70 (1958).
[2] R. B. Walton, N. F. Wikner, J. L. Wood, and J. R. Beyster, Bull. Am. Phys. Soc. Ser. II, 5, 288 (1960); P. A. Egelstaff, J. Nuclear Energy 5, 203 (1957).
[3] Generously provided by E. D. Stover of the General Electric Research Laboratory.
[4] Private communication.

D2. Isotopic Identification of Neutron Resonances in Cd from Capture Gamma-Ray Spectra.* H. E. JACKSON AND L. M. BOLLINGER, *Argonne National Laboratory.*—The customary method of isotopic identification of slow neutron resonances has been the comparison of transmission measurements on samples of separated isotopes of the element under study. We have attempted to demonstrate that, with the aid of a new 3-dimensional analyzer, identification often may be made more effectively and rapidly by the study of γ-ray spectra from neutron capture in resonances of the natural element. For this purpose, resonances in cadmium were studied by the observation of coincident capture γ rays in two NaI(Tl) scintillators. The three parameters describing events of this kind (2 pulse heights and a neutron time-of-flight) were digitally recorded on magnetic tape for later analysis. Identification of resonances was made primarily by the observation of the characteristic γ rays that result from decay of the low-energy states of the several product nuclides. The measurements which were completed in less than one-tenth the time that would have been required for transmission measurements on separated isotopes resulted in the identification of 23 resonances between 18 and 235 ev. One resonance (at 59 ev) was previously undetected, and five others were previously unidentified. The data lead to the following values of the average observed level spacing: 30 ev for Cd^{111}, 80 ev for Cd^{112}, and 27 ev for Cd^{113}, as determined from 8, 3, and 9 levels, respectively.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

D3. Capture Gamma Rays from $Cd^{113}(n,\gamma)Cd^{114}$.* R. K. SMITHER, *Argonne National Laboratory.*—The spectra of capture gamma rays below 2 Mev for $Cd^{113}(n,\gamma)Cd^{114}$ were measured with the Argonne 7.7-m bent-crystal spectrometer. A total of 119 gamma rays were observed. Their intensities varied from 88 photons per 100 neutron captures to 0.003 photon per 100 neutron captures. The precision of these measurements varied from 1 part in 1000 to 1 part in 20 000. A series of coincidence experiments were performed to determine which of these gamma rays were in coincidence with each other. The precision measurements of the gamma ray energies and the coincidence experiments were used to revise the existing level scheme of Cd^{114}. Evidence for five new levels is presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

D4. Scattering of Fast Neutrons from Tungsten.* A. B. SMITH AND P. A. MOLDAUER, *Argonne National Laboratory.*—Fast time-of-flight techniques are utilized to study the scattering of fast neutrons from natural tungsten. The incident neutron energy range extends from 0.3 to 1.5 Mev. Inelastically scattered neutrons leaving the residual nucleus in the first excited state are studied in detail. The average excitation energy of the first level is measured to be 120 kev. This "average" energy is shown to consist of contributions from the even-even isotopes of natural tungsten. The angular distribution of elastically scattered neutrons is measured. The angular dependence of the cross section for inelastic scattering to the first level in tungsten is determined. Inelastic scattering resulting in the excitation of higher residual nuclear levels including states at 350, 650, and 950 kev is studied. The experimental results are compared with theoretically calculated inelastic excitation functions and angular distributions.

* This work supported by the U. S. Atomic Energy Commission.

D5. Gamma Rays Produced by Inelastic Neutron Scattering on Strontium.* S. M. SHAFROTH, R. W. JACKIW, AND D. M. VAN PATTER, *The Bartol Research Foundation.*—The gamma spectrum arising from neutron bombardment of strontium has been studied for neutron energies of from 1.0 Mev to 3.4 Mev in 0.2-Mev steps. The neutrons were produced by the proton beam of the Bartol-ONR generator which impinged on lithium targets 50-kev thick. A 35-mm × 40-mm NaI(Tl) cylinder was used to detect the gammas. The following gammas have been observed: 0.51, 0.80, 0.91, 1.08, 1.16, 1.23, 1.37, 1.84, 2.14 Mev (±1%). Most of these arise from inelastic neutron scattering in Sr^{88} and Sr^{86}. The experimental cross sections for some of these gammas have been compared with cross sections calculated by the Hauser-Feshbach method using transmission coefficients derived from diffuse surface potential wells of Emmerich,[1] Campbell *et al.*,[2] and Beyster *et al.*[3] From the comparison with theory for different spins and parities it is concluded that the second 2+ level in Sr^{86} occurring at 1.88 Mev most probably has been found. The angular distribution of the 1.84-Mev gamma has been measured at an average neutron energy of 2.2 Mev. It will be compared with the angular distribution predicted using Satchler's theoretical expression.

* Assisted in part by the U. S. Atomic Energy Commission.
[1] W. S. Emmerich, Westinghouse Research Rept. 6-94511-6-R19 (April, 1958).
[2] Campbell, Feshbach, Porter, and Weisskopf, MIT-LNS Tech. Rept. No. 73 (February, 1960).
[3] Beyster, Schrandt, Walt, and Salmi, LA-2099 (April, 1957).

D6. Fast-Neutron Total Cross Sections of Helium.* D. B. FOSSAN, *University of Wisconsin.*—The total neutron cross section of helium was measured at four energies between

7 Mev and 12 Mev by a transmission experiment with a high-pressure gas cell.[1] Neutrons of about 80-kev energy spread were produced by bombarding a deuterium gas target with deuterons from a tandem electrostatic accelerator. A stilbene scintillator with pulse shape γ-ray discrimination served as a biased proton recoil detector. The measured cross sections, listed in Table I, have a statistical uncertainty of about 2.5%.

TABLE I.

Energy (Mev)	Cross section (Barns)
6.99	1.90
8.03	1.66
10.07	1.37
12.01	1.26

These data are in good agreement with a curve connecting previous measurements at lower and higher energies.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] On loan from Dr. M. Walt, Lockheed Missiles and Space Research Laboratory.

D7. Total Neutron Cross Section of Pb^{208}. E. C. CAMPBELL AND J. L. FOWLER, *Oak Ridge National Laboratory.*—The total neutron cross section of Pb^{208} is obtained from transmission measurements made on two samples of naturally occurring Pb of different isotopic abundances of 206, 207, 208. One sample, extracted from Tennessee shale, has relative abundances (26.7, 2.0, 71.3); the other, a radiogenic Pb, is characterized by (88.3, 8.6, 3.0). By subtraction the "equivalent" sample has composition (−0.9, 0.0, 99.1). With a $T(p,n)$ neutron source of 20-kev energy spread the cross section was measured from 0.55 to 4.32 Mev. A portion of this energy range was remeasured at 10-kev resolution with a $Li(p,n)$ source. The neutron detector was a propane recoil counter. Besides the previously identified $\frac{3}{2}$ level at 0.73 Mev[1] and a broad $\frac{3}{2}$ level at 1.735 Mev[2] a $J=\frac{1}{2}$ level 40 kev wide was observed at 0.83 Mev. A large number of new levels was found with an approximate spacing of 100 kev in the region 0.6 to 2.6 Mev. It is planned to repeat the measurements with better resolution to investigate whether the narrow 1.850- and 1.760-Mev levels could be the result of high angular momentum states.

[1] R. E. Peterson, R. K. Adair, and H. H. Barschall, Phys. Rev. 79, 935 (1950).
[2] J. L. Fowler, Bull. Am. Phys. Soc. Ser.II, 5, 443 (1960), this issue.

D8. Left-Right Asymmetry in the Scattering of Polarized Neutrons from Light Nuclei.* A. J. ELWYN AND R. O. LANE, *Argonne National Laboratory.*—By use of neutrons emerging at an angle of 51° in the $Li^7(p,n)Be^7$ reaction, the left-right asymmetry in the scattering from samples of Li^6, Li, Be, B, C, O, and Mg has been measured at the laboratory angles of 45° and 90° in various energy ranges from 150 to 2400 kev. In the region around the 250-kev scattering resonances, the magnitude and energy dependence of the asymmetry in normal Li and Li^6 are considerably different, the normal Li showing a larger asymmetry. From about 300 to 2400 kev, the asymmetry at 45° in normal Li has an almost constant value of 20% and is near zero at 90°. Large values for the asymmetry were found for Mg at the 260-kev resonance. The measurements on Be near the 620-kev state, and on B near the 430-kev resonance, show small values for the asymmetry, i.e., maximum values of about 10% for Be, 15% for B. The asymmetry becomes somewhat larger at higher energies. The asymmetry in C is small up to 1500 kev. Measurements were made for O from 200 to 2200 kev, with good resolution near the 430-kev resonance. In this region the results at both angles are consistent with a value of 32% for P_1. Reasonable values for the s- and p-wave phase shifts were used to calculate the values of P_2 at all energies in the vicinity of the resonance.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

D9. Neutron Yields of D+D and p+T.* W. E. WILSON, D. B. FOSSAN, AND R. L. WALTER, *University of Wisconsin.*—The neutron yields at zero degrees of the reactions $D(d,n)He^3$ and $T(p,n)He^3$ were measured from 4.9- to 13.4-Mev bombarding energy at intervals of about 500 kev. Gas targets containing deuterium or tritium were bombarded with deuterons or protons from a tandem electrostatic accelerator. The neutron flux was measured with a proton recoil counter telescope. Good agreement is found with other measurements of the $D(d,n)He^3$ cross section. When the relative yield of the $T(p,n)He^3$ reaction is normalized to a value of 67 mb/sr at 4.9 Mev, the cross section has a minimum of 26 mb/sr at 10 Mev and increases to 36 mb/sr at 13.4 Mev. The cross section for neutrons at zero degrees from the breakup process $D(d,np)D$ was measured at about 1-Mev intervals from 8.9- to 12.9-Mev deuteron energy and increases from 71 to 185 mb/sr. No neutrons from the process $T(p,np)D$ were observed at a proton energy of 11.9 Mev, and the upper limit placed on the cross section at that energy is 10 mb/sr.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds provided by the Wisconsin Alumni Research Foundation.

D10. Disintegration of Ne and Kr by Fast Neutrons.* R. E. SHAMU, W. BENENSON, AND R. L. WALTER, *University of Wisconsin.*—A high-pressure gas scintillation counter filled with Ne or Kr was used to measure their disintegration cross sections for neutron bombardment. The $D(d,n)He^3$ reaction served as the source of neutrons. Neutron flux measurements were made with a proton recoil counter telescope. For Ne, five groups of alpha particles were observed corresponding to transitions to the ground and the first four excited states of O^{17}. The total (n,α) cross section from 6.1 to 9.0 Mev and the cross section for alpha transitions to the ground plus first excited state of O^{17} from 6.1 to 11 Mev were measured with a neutron energy spread of about 65 kev. For Kr, no groups of charged disintegration particles were resolved. Spectra of the disintegration particles were taken at neutron energies from 6.4 Mev to 12 Mev in about 500-kev steps with a neutron energy spread of about 150 kev. The cross section for disintegration by charged particle emission increased monotonically from 5 mb at 6.4 Mev to 25 mb at 12 Mev.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

D11. Angular Distributions in $n-\alpha$ Elastic Scattering.* S. M. AUSTIN AND R. E. SHAMU, *University of Wisconsin.*—Angular distributions of neutrons scattered from He^4 have been measured by observing the energy spectrum of the recoil alpha particles in a high-pressure gas scintillation counter filled with a He-Xe mixture. This spectrum is directly proportional to the differential cross section as a function of the cosine of the scattering angle θ in the center-of-mass system. Measurements were made at twelve neutron bombarding energies between 1 and 21 Mev. In most cases data were obtained for $\theta \gtrsim 60°$. The gas pressure was adjusted (between 100 and 800 psi) so that wall effects were less than 5% at neutron energies below 15 Mev. The measured angular distributions will be compared with cross sections calculated from the phase shifts given by Seagrave.[1]

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] J. D. Seagrave, Phys. Rev. 92, 1222 (1953).

D12. Energy Dependence of Fission Fragment Anisotropies.* R. VANDENBOSCH, H. WARHANEK, AND J. R. HUIZENGA, *Argonne National Laboratory.*—The dependence of the

angular distributions on projectile energy for helium-ion-induced fission of Th^{232}, U^{233}, and U^{238} has been investigated using solid-state fission fragment detectors.[1] The measurements cover the range of projectile energies between 20 and 43 Mev in steps of 1 Mev or less. The energy dependence of the anisotropy has a structure which is in qualitative agreement with theoretical predictions.[2] The most fissionable target studied, U^{233}, shows the least structure, while the least fissionable target, Th^{232}, shows the most structure, demonstrating that large anisotropies result from fission occurring at low excitation energy following neutron emission from the compound nucleus. The energy dependence of K_0, the standard deviation of the distribution in the angular-momentum projection on the nuclear symmetry axis at the saddlepoint, has been deduced from this and other data[3] on angular distributions from neutron-induced fission.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] We are indebted to D. M. Sparlin for supplying excellent solid state detectors.

[2] I. Halpern and V. M. Strutinskii, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, P/1513, p. 408.

[3] J. E. Simmons and R. L. Henkel (unpublished data).

FRIDAY MORNING AT 10:00

Social Sciences 122

(W. J. CHILDS presiding)

Hyperfine Structure and Nuclear Paramagnetic Resonance

E1. Hyperfine Structure in the Arc Spectrum of Argon 37.* MERTON M. ROBERTSON AND J. E. MACK, *University of Wisconsin*, AND V. W. COHEN AND RAYMOND DAVIS, *Brookhaven National Laboratory*.—The nuclear spin and nuclear magnetic moment of argon 37 have been determined by high-resolution optical spectroscopic methods with a Fabry-Perot interferometer. The A^{37} was produced through the $Ca^{40}(n\alpha)A^{37}$ reaction by pile neutron irradiation of CaF_2. The A^{37}, which has a half-life of 34.1 days, was extracted, purified, and loaded into an electrodeless discharge tube, which was liquid-air-cooled in operation. The source initially contained 1.6 μg of A^{37}, contaminated by about an equal amount of A^{40}. The A^{40} permitted the determination of the isotope shift of A^{37} with respect to A^{40} in some levels. The levels investigated were primarily those of the $3p^54s$ and $3p^54p$ configurations; hyperfine structure energy level diagrams were established for all the terms of these configurations. The nuclear spin was determined by application of the interval rule and by intensity considerations to be $\frac{3}{2}$, in good agreement with the single-particle shell model theory prediction of a $d_{\frac{3}{2}}$ nuclear ground state. The nuclear magnetic moment was determined from the hyperfine splittings in the $3p^54s$ configuration, using the theory of intermediate coupling, to be 0.97 ± 0.30 nm.

* This work was supported by the Wisconsin Alumni Research Foundation, the National Science Foundation, the Department of the Army Ordnance Corps, and the U. S. Atomic Energy Commission.

E2. Measurement of $g_J(Ag,^2S_{\frac{1}{2}})$ Relative to $g_J(H,^2S_{\frac{1}{2}})$.* G. S. HAYNE AND H. G. ROBINSON, *Yale University*.—Low magnetic field ($\sim$9 gauss) $\Delta F=0$, $\Delta m_F=\pm1$ transitions have been observed in the $^2S_{\frac{1}{2}}$ electronic ground state of the $Ag^{107,109}$ isotopes by means of exchange polarization and detection with optically polarized Rb. The resonances were seen both with static and with flowing He buffer gas. Primarily because of the uncoupling of I and J by the applied magnetic field, each isotope (107, 109) exhibits two Zeeman resonances, line widths $\leq$1.5 kc, separated by 196 kc and 170 kc, respectively. The measurement reported here was made using the buffer-flow technique with a He pressure of $\sim$10 cm Hg. Hydrogen admitted upstream relative to the Ag permitted observation of both H and Ag resonances simultaneously. The applied magnetic field was locked to a stable fixed frequency oscillator via one of the Rb^{85} resonances. A long-term field stability of 2×10^{-6} was obtained. If the spatial distribution of H and Ag in the region of observation is the same, a measurement of g_J(Ag) relative to g_J(H) is possible. The result without pressure-shift correction is $g_J(Ag)/g_J(H)=1.000028(10)$. Further consideration is being given the possibility of a spatial distribution error.

* This work has been supported by the U. S. Army Signal Corps.

E3. Isotope Shift in the Arc Spectrum of Nickel. DANIEL J. SCHROEDER AND J. E. MACK,* *University of Wisconsin*.—The isotope shift in 31 spectral lines in the nickel arc spectrum has been determined by the use of a Fabry-Perot interferometer. The relative shifts of levels of 4 configurations were deduced from the observed line shifts, these being the complex configurations, $3d^84s^2$ and $3d^84s4p$, and the two-electron configurations, $3d^84s$ and $3d^84p$. Shifts caused by the specific mass effect were shown to be a significant part of the observed shifts. By noting the deviations of the ratios of shifts between adjacent pairs of even isotopes from those predicted by the mass effect theory it was possible to deduce the relative field effect. The arrangement of neutrons in the outermost nuclear shells is believed to account for the observed relative shifts between adjacent even isotopes.

* Currently on leave as Scientific Attaché, Stockholm, Sweden.

E4. Nuclear Spin and Hfs of Ge^{71}.* W. J. CHILDS AND L. S. GOODMAN, *Argonne National Laboratory*.—The 12-day isotope Ge^{71} has been investigated by means of the atomic-beam magnetic-resonance technique. The nuclear spin is found to be $\frac{1}{2}$. The hfs-separations have been measured in both the $^2P_1$ and $^2P_2$ levels of the $^2P_{\frac{1}{2},\frac{3}{2}}$ atomic ground state. The results are $\Delta\nu(^2P_1)=87\pm1$ Mc/sec and $\Delta\nu(^2P_2)=357\pm8$ Mc/sec. All of the measurements are based on observations of double-quantum transitions of the type $\Delta F=0$ at fields up to 70 gauss.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

E5. Optical Detection of Level Crossings in $Cd^{111,113}$.* M. N. MCDERMOTT, R. NOVICK, AND P. THADDEUS, *Columbia Radiation Laboratory*.—The effect on resonance fluorescence of level crossings in a magnetic field, discovered by Franken *et al.*[1] for fine structure components in He, has been observed for hyperfine levels of the $5s5p^3P_1$ state of Cd^{111} and Cd^{113}. A single crossing point, expected on the basis of the known values of g_J and A^2 has been found for each isotope with a signal-to-noise ratio of better than 50:1 when using narrow-band detection of the 3261 A intercombination line fluorescence. Preliminary measurements place the crossing points near 1965 and 2056 gauss for Cd^{111} and Cd^{113}, respectively, or within present field uncertainties of the calculated values. The observed line width of about 0.6 gauss, however, contrasts sharply with the 0.05

gauss expected from the 2.5-μsec lifetime of the $3P_1$ state and is due to field inhomogeniety. Refinements in line width and field measurement will permit a precise determination of g_J in terms of A for either isotope.

* Work supported by the U. S. Air Force.
[1] F. D. Colegrove, P. A. Franken, R. R. Lewis, and R. H. Sands, Phys. Rev. Letters **3**, 420 (1959).
[2] R. F. Lacey, Quarterly Progr. Rept., Research Lab. Electronics, MIT April, 1959, p. 49; January, 1959, p. 32 (unpublished).

E6. Hfs and Isotope Shift in Radio-Thallium 199 and 200.* R. J. HULL AND H. H. STROKE, *MIT.*—The hyperfine structure and isotope shifts of the 3776 A and 5350 A lines of two radioactive isotopes of thallium, Tl^{199} (7.4 hr) and Tl^{200} (27 hr), have been measured spectroscopically. The isotopes were produced by alpha bombardment of gold in the MIT cyclotron and were excited in electrodeless discharge lamps. The dispersing element of the spectrograph was a 10-in. grating, used in a 40-ft mirror monochromator. Measurements of these two lines give $\Delta\nu(6s^26p^2P_{\frac{3}{2}}) = 693\pm7\times10^{-3}$ cm^{-1} and $\Delta\nu(6s^27s^2S_{\frac{1}{2}}) = 398\pm6\times10^{-3}$ cm^{-1} for Tl^{199}. The Tl^{200} patterns appeared as single lines, indicating that the hfs was less than 0.040 cm^{-1}. The resulting magnetic moments calculated by comparison with the stable thallium hfs and moments, with the Bohr-Weisskopf effect neglected, are $+1.57$ NM and $|\mu| < 0.15$ NM for Tl^{199} and Tl^{200}. The isotope shift relative to Tl^{205} in the ultraviolet line is -0.164 ± 0.004 cm^{-1} for Tl^{199} and -0.148 ± 0.004 cm^{-1} for Tl^{200}. The isotope displacements in the green line are -0.177 ± 0.004 cm^{-1} and -0.169 ± 0.004 cm^{-1} for Tl^{199} and Tl^{200}, respectively, relative to Tl^{205}.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

E7. Tritium Hyperfine Splitting.* F. M. PIPKIN AND R. H. LAMBERT, *Harvard University.*—The spin-exchange optical polarization method has been used to redetermine the hyperfine splitting of atomic tritium. The measurement was made by observing the ($F=0$, $m=0\rightarrow F=1$, $m=1$) and the ($F=0$, $m=0\rightarrow F=1$, $m=-1$) hyperfine transitions. The line width was mainly the result of inhomogenities in the earth's magnetic field over the 500-cm^3 absorption flask and of 60-cycle magnetic fields. A feedback system was used to reduce the 60-cycle fields, and the static field was shimmed by placing several small cylindrical bar magnets around the apparatus. By carefully adjusting the position of these magnets the full width at half-maximum was reduced from 1400 cps to 300 cps. The measurements were made in argon and neon buffer gases, and the hyperfine splitting was obtained by extrapolating to zero pressure. Three bulbs were made for each gas, and all of the measured points lay on a straight line to within the 2-cps probable error with which each point was determined. A preliminary value for the zero field hyperfine splitting is 1516.701476$\pm$0.000010. The fractional pressure shifts (pressure shift divided by hyperfine splitting) are the same as those found for deuterium in argon and neon.[1]

* Research supported in part by the Sloan Foundation and in part by the National Science Foundation.
[1] L. W. Anderson, F. M. Pipkin, and J. C. Baird, Jr., Phys. Rev. Letters **4**, 69 (1960).

E8. Heavy Absorption of a Spectral Line.* ROBERT H. KOHLER,† *MIT.*—Light from a single spectral line passes through a gas that has a single absorption resonance. We call the ratio of the transmitted to the incident flux the "average transmission." Closed-form expressions for the average transmission have been derived[1] for the following conditions: (1) The incident and absorbing lines are each of pure Doppler shape. (2) There is no scattering coherence between the different absorbing molecules of the gas. (3) The average transmission is small. (4) The incident and absorbing lines, in general, are of different temperatures. (5) The incident and absorbing lines, in general, are centered at different wave numbers. Condition (5) may result from isotope structure or magnetic fields. For optical-scattering applications, conditions (1) and (2) are approximations.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Air Research and Development Command), and the U. S. Navy (Office of Naval Research).
† Present address: Columbia Radiation Laboratory.
[1] R. H. Kohler, Quarterly Progr. Rept. No. 52, Research Laboratory of Electronics, MIT, January 15, 1959, p. 32.

E9. Hyperfine Structure of the Forbidden Lines in the Spectrum of BiII.* C. DANIEL COLE, *Bell Aerosystems Company.*—The observation of five forbidden lines, corresponding to transitions between the five lowest levels of BiII, each level belonging to the electron configuration $6s^26p^3$, was reported previously.[1] Photographs of the hyperfine structure of each of these lines have been made recently using Fabry-Perot etalons. The lines studied were $\lambda3241(^1S_0-{}^3P_1)$, $3683(^1S_0-{}^3P_2)$, $4850(^1D_2-{}^3P_1)$, $5914(^1D_2-{}^3P_2)$, and $7503(^3P_1-{}^3P_0)$. The last line, $\lambda7503$, is a pure magnetic dipole line observed for the first time as a nonintercombination transition. The hyperfine structure splitting factors and the quadrupole coupling constants for the levels involved were calculated directly from experimental data and these values compared with values obtained theoretically. The procedure for calculation of the quadrupole coupling constants as originally given by Casimir has been extended to include the case of two equivalent p electrons. The theory and experiment are found to agree quite satisfactorily.

* This research was performed at the Department of Physics, University of Buffalo.
[1] C. D. Cole and S. Mrozowski, Phys. Rev. **93**, 933 (1954).

E10. Pure Nuclear Quadrupole Resonances in Cadmium Halides.* S. L. SEGEL, R. G. BARNES, AND W. H. JONES, JR.,† *Iowa State University.*—Pure nuclear quadrupole resonances of Br^{79} and Br^{81} and of I^{127} have been detected in polycrystalline samples of $CdBr_2$ and CdI_2, respectively. The quadrupole coupling constants for the observed resonances at 77°K are 34.086 Mc/sec for Br^{79} and 95.54 Mc/sec for I^{127}. Within the experimental error, the asymmetry parameter for the I^{127} coupling constant is zero. All of the resonance frequencies exhibit positive temperature dependence, increasing with increasing temperature. For I^{127} in CdI_2, $(1/\nu)(\partial\nu/\partial T) = 0.5\times10^{-4}$ deg^{-1}, and for Br^{79} in $CdBr_2$, $(1/\nu)(\partial\nu/\partial T) = 0.3\times10^{-4}$ deg^{-1}. The cadmium halides are normally considered to be predominantly ionic in the solid state, and the small value of the observed halogen coupling constants confirms this. The appropriateness of a purely ionic model[1] for the origin of the electric field gradients causing the nuclear quadrupole interaction will be discussed.

* This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† Present address: IBM Laboratories.
[1] R. Bersohn, J. Chem. Phys. **29**, 326 (1958).

E11. Pure Quadrupole Spectrum of Cl^{35} in $AgClO_3$ and NH_4ClO_3. L. WILMER ANDERSON AND WILLIAM J. GOODWIN, *University of Wisconsin.*—The pure quadrupole spectra of Cl^{35} in polycrystal samples of $AgClO_3$ and NH_4ClO_3 have been studied. Very pure samples were prepared by the exchange reaction involving the metal sulfate and $Ba(ClO_3)_2$. The $AgClO_3$ crystals were prepared by evaporation of a water solution. The NH_4ClO_3 was prepared by lyophilization because of the compound's explosive nature. The spectra of these chlorates were examined with a superregenerative oscillating detector. The resonant frequencies in $AgClO_3$ and NH_4ClO_3, respectively, were 28.84 and 28.46 Mc/sec at $T=25$°C. The temperature coefficient of each of these frequencies was about -4 kc/°C at $T=25$°C. These frequencies are quite close to other Cl^{35} quadrupole resonances in chlorates.[1]

[1] P. J. Bray, J. Chem. Phys. **23**, 704 (1955).

E12. Steady-State Nuclear Induction Signal Shapes in Lithium Metal.* W. H. JONES, JR.,† D. R. TORGESON, AND R.

G. BARNES, *Iowa State University*.—A detailed theoretical and experimental study has been completed of the absorption and dispersion mode nuclear magnetic resonance signals for Li^7 in solid lithium metal at room temperature. Calculations of resonance signal shapes, based on the Bloch theory[1] as modified by the small-amplitude modulation theory of Halbach,[2] were made with an IBM650 computer and were compared with the experimental results. A variety of experimental conditions and both the in-phase and quadrature components of the signal at the modulation frequency were studied. The Bloch-Halbach theory appears to account very satisfactorily for the saturation behavior of the four types of resonance signals. In addition, the behavior of the complex absorption mode signal provides a convenient means of determining with precision the location of the quadrature phase signal.

* This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† Present adress: IBM Laboratories.
[1] F. Bloch, Phys. Rev. **70**, 460 (1946).
[2] K. Halbach, Helv. Phys. Acta **27**, 259 (1954).

E13. Nuclear Quadrupole Resonance of Metallic In^{115}. W. O'SULLIVAN, W. A. ROBINSON, AND W. W. SIMMONS, *Space Technology Laboratories, Inc.*—The In^{115} $m=9/2 \rightarrow 7/2$ NQR transition in a powder sample of metallic indium has been followed with a superregenerative detector from 77°K to 429°K, the indium melting point. This work represents an extension to higher temperatures of previous measurements.[1,2] The resonance frequency drops from 5 Mc/sec at room temperature to approximately 3 Mc/sec at 428°K. It seems probable that a careful band structure calculation must be performed, including the effect of lattice parameter changes upon the conduction band p character, before the strong temperature dependence of the indium electric field gradient can be explained adequately. The resonance line width remains approximately constant throughout the temperature range investigated.

[1] R. R. Hewitt and W. D. Knight, Phys. Rev. Letters **3**, 18 (1959).
[2] C. P. Slichter and W. W. Simmons (to be published).

FRIDAY MORNING AT 10:00

Rosenwald 2

(E. N. PARKER presiding)

Plasma Physics

F1. (Abstract withdrawn.)

F2. (Abstract withdrawn.)

F3. Ionization Cross Sections for Protons on Hydrogen Gas in the Energy Range 0.15–1.10 Mev.* J. W. HOOPER, E. W. MCDANIEL, D. W. MARTIN, AND D. S. HARMER, *Georgia Institute of Technology*.—Measurements have been made of the ionization cross section for protons incident on hydrogen gas in the energy range 0.15–1.10 Mev. The experiment was conducted under "thin" target conditions. Ions and electrons produced in ionizing collisions were collected on electrodes mounted parallel to the beam axis, and the resulting currents were measured with electrometers. Segmented electrode structures were used to define the effective collision volume, and grid structures provided for suppression of secondary electrons. Corrections were made for background gas contributions. The experimental cross section in this energy region can be represented by

$$\sigma_i = (3.45 \pm 0.20) E^{-(0.870 \pm 0.005)} \times 10^{-17} \text{ cm}^2/\text{molecule}.$$

Our result is in excellent agreement with an approximate extension to the present molecular case of a Born approximation calculation[1] of the cross section for the atomic process $H^+ + H^0 \rightarrow H^+ + H^+ + e$. Measurements on target gases other than hydrogen are in process and are discussed.

* This research was supported by the Controlled Thermonuclear Division of the U. S. Atomic Energy Commission.
[1] D. R. Bates and G. Griffing, Proc. Phys. Soc. (London) **A66**, 961 (1953).

F4. Radio-Frequency Noise of a Langmuir Probe in a Plasma. R. D. SEARS AND JAMES J. BROPHY, *Armour Research Foundation*.—Zaitsev *et al.*[1] have measured noise at an immersed probe in a hot cathode discharge plasma and describe a maximum noise power when the probe was near plasma potential. Results of experiments in this laboratory on a dc cold cathode glow discharge plasma indicate a minimum when the probe is near plasma potential, apparently contradicting Zaitsev's results. The variation of noise power vs probe current has been measured and suggests the source of the contradiction One would expect a shot noise to be present when the probe is drawing an electron current, and this is observed. However, at negative probe potentials the noise power does not exhibit the same characteristic and is tentatively explained as being the result of "cathode" noise. Near zero net probe current, the background noise observed results from "cathode" noise of the tube, plasma noise, and possibly a very small shot noise component. It is concluded that Zaitsev's method for determining plasma potential is not generally applicable.

[1] A. A. Zaitsev, M. Ya. Vasil'eva, and V. N. Mnev, Soviet Phys.—JETP (English) **9**, 1130 (1959); (Russian) **36**, 1590 (1959).

F5. Experimental Observations of High-Velocity Plasma Interactions.* DALE J. DEGEETER, *Armour Research Foundation*.—Two high-velocity plasmas (plasmoids) of similar origin propagating parallel to each other have been observed to interact, resulting in a mutual repulsion. A simplified analysis of an electric or magnetic dipole moment plasmoid configuration has been made to gain insight into the mechanism involved. The new source, consisting of two "button" sources in series, appears to produce two plasmoids of very similar optical characteristics. Photographs of the plasmoids and their trajectories will be presented and discussed as a function of the experimental parameters.

* Work supported by the Air Research and Development Command, U. S. Air Force.

F6. Transport Phenomena in Inhomogeneous Ionized Gases. MAHENDRA SINGH SODHA, *Armour Research Foundation*.—Various transport phenomena are considered in the presence of a high electric field (ac+dc), magnetic field, and temperature gradient in a nonuniform ionized gas having gradients of electron density and collision frequency. Expressions for electrical and thermal currents have been derived which are valid for a slightly ionized gas as well as highly ionized gas when the various parameters, affecting the distribution function, are small enough to keep the isotropic part of the distribution function essentially Maxwellian. A differential equation for the isotropic part of distribution function also has been set up. The application of the analysis to determination of transport

properties and investigation of electromagnetic wave propagation in a nonuniform ionized gas also has been indicated.

F7. Absorption of Carbon Dioxide at 4.40 μ.* MARTIN STEINBERG AND WILLIAM O. DAVIES, *Armour Research Foundation.*—The absorption of carbon dioxide nitrogen mixtures at 4.40 μ was examined over a temperature range of 1200°K for optical densities of 0.10 atm-cm to 0.23 atm-cm. The test gas was elevated to desired temperatures by shock compression. Properties of the test gas were determined by measurement of initial concentrations and shock wave velocities. Absorption was observed as a diminution of source beam intensity monitored with a rapid response infrared detector and displayed on an oscilloscope. Beer's law was found to be applicable over the range of temperature and concentration studied. Absorption coefficients were found to be 3 atm^{-1} cm^{-1} and varied by only 10% over this temperature interval. The absorption was also measured over a wavelength of 4.37 to 4.46 μ. Absorption coefficients were independent of total pressure, indicating the absence of pressure broadening. The results of this investigation are compared to the existing theoretical and experimentally determined absorption data.

* Work supported by the Air Research and Development Command, U. S. Air Force.

F8. Shock-Tube Study of Vibrational Relaxation in the $A^2\Sigma^+$ State of NO.* WALTER ROTH, *Armour Research Foundation.*—Nonequilibrium No-γ-band emission was observed behind incident shock waves in rare gas-air mixtures in the approximate temperature range, 5000–10 000°K. Probabilities P_{10} for collisional de-excitation from $v'=1$ to $v'=0$ in the $A^2\Sigma^+$ state were calculated from measured relaxation times τ_{10}. The latter were obtained from measurements of the relative temporal behavior of $\gamma(1,1)$ and $\gamma(0,0)$ band emission behind the shock waves. P_{10} ranged from about 3×10^{-5} at 5000°K to about 3×10^{-4} at 10 000°K and exhibited the usual $\exp(-T^{-\frac{1}{3}})$ dependence. It appears that theoretical treatments of vibrational relaxation[1,2] apply to excited electronic states of relatively nonpolar molecules as well as to ground states. It will be shown that the crossings of electronic energy levels of NO are such that the total vibrational relaxation time for NO($A^2\Sigma^+$) from the time of formation from atoms is only about 1.8 τ_{10}.

* Work supported by the Bendix Corporation under contract to the U. S. Army Rocket and Guided Missile Agency.

[1] H. A. Bethe and E. Teller, "Deviations from thermal equilibrium in shock waves," Ballistic Research Labs. Rept. X117 (1941).
[2] K. E. Herzfeld, *Thermodynamics and Physics of Matter* (Princeton University Press, Princeton, New Jersey, 1955), p. 646.

F9. On the Interaction of Microwaves in the Wake of a Hypervelocity Projectile.* THADDEUS KALISZEWSKI, *Sylvania Electronic Systems.*—The phenomenon of interaction between two electromagnetic waves traversing the same region in an ionized medium, such as the ionosphere or a gaseous discharge, provides a powerful tool for the study of the fundamental gas kinetic processes responsible for the formation, maintenance, and decay of the medium. The utility of this phenomenon has been demonstrated by, among others, Anderson and Goldstein,[1] who were able to measure, for instance, the probability of collision for momentum transfer P_e in an afterglow of an electrical discharge in helium. The present study purports to show that it may be feasible to use this phenomenon to study the parameters of ionization in the wake of a hypervelocity projectile. Of special interest in this study is the relaxation time associated with the interaction, inasmuch as its measurement and interpretation do not appear to depend on the assumed configuration of the wake. This property is discussed and feasibility questions considered, including an estimate of ionization parameters believed to be typical of the wakes generated by a small hypervelocity projectile. The experimental criteria such as detectability, frequencies, radiated power, bandwidth, and modulation are specified.

* This work is performed under the joint auspices of ARPA and ARGMA.
[1] J. M. Anderson and L. Goldstein, Phys. Rev. **100**, 1037 (1955).

Post-Deadline Papers, If Any

FRIDAY AFTERNOON AT 2:00

Mandel Hall

(R. HILDEBRAND presiding)

Invited Papers in High-Energy Physics

G1. The $\bar{K}$-Nucleon Interaction. RICHARD H. DALITZ, *University of Chicago.* (30 min.)
G2. Pion—Hyperon Resonances. MYRON L. GOOD, *University of Wisconsin.* (30 min.)
G3. What We Can Learn about Elementary Particles from Superconductivity. YOICHIRO NAMBU, *University of Chicago.* (30 min.)
G4. Vector Theory of Strong Interactions. J. J. SAKURAI, *University of Chicago.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Kent 106

(J. L. OLSEN presiding)

Invited Papers on He^3

H1. A Possible Low-Temperature Superfluid Phase of Liquid He^3. A. M. SESSLER, *Ohio State University.* (30 min.)
H2. Recent Experiments on Nuclear Resonance in Liquid and Solid He^3. HORST MEYER, *Duke University.* (30 min.)
H3. Some Experiments on He^3 at Very Low Temperatures. J. C. WHEATLEY, *University of Illinois.* (30 min.)
H4. The Melting Curve of He^3 below the Minimum. D. O. EDWARDS, *Ohio State University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Breasted Hall, The Oriental Institute

(A. L. SCHAWLOW presiding)

Optical Properties of Solids

I1. Thermoluminescence of Postassium Azide. H. J. MUELLER AND H. D. TILLER, *U. S. Army Engineer Research and Development Laboratories.*—The thermoluminescence of potassium azide was studied by means of an UV-sensitive photomultiplier. Glow curves were taken in the temperature range from −190°C to +400°C. Both untreated and UV-irradiated samples emitted light when thermolytically decomposed. The glow curves of UV-irradiated samples displayed additional peaks between −150°C and −50°C which are ascribed to the extinction of color centers. The spectral characteristics of the emitted radiation were investigated. The results obtained are related to previous work on color centers[1] and exo-electron emission[2] of potassium azide. Measuring techniques are described.

[1] F. C. Tompkins and D. A. Young, Proc. Roy. Soc. (London) **A236**, 10 (1956).
[2] H. J. Mueller, Bull. Am. Phys. Soc. Ser. II **5**, 281 (1960).

I2. Effect of Configuration Mixing and Covalency on the Energy Spectrum of Ruby. S. SUGANO* AND M. PETER, *Bell Telephone Laboratories, Inc.*—For the purpose of improving the analysis hitherto done[1] of the optical and microwave spectrum of ruby, a calculation has been performed in the strong cubic field scheme, taking into account the effect of configuration mixing of the higher excited t_2^2e states into the t_2^3 states. In the calculation, covalency of the t_2 and e electrons is also introduced in a simplified fashion besides the spin-orbit interaction, trigonal field, and Zeeman energy. The result shows that the configuration mixing and the covalency play very important roles in giving zero-field splittings and g-values of the t_2^3 states. It is also found that there is not much difference in the degrees of covalency for the t_2 and e electrons, although they are fairly large for both electrons. The best zero-field splitting of the ground quartet thus obtained is 0.24 cm^{-1} with the correct sign. The authors appreciate greatly the contribution of Miss B. B. Cetlin to the numerical side of this work.

* On leave from the Department of Physics, Tokyo University, Tokyo, Japan.
[1] S. Sugano and Y. Tanabe, J. Phys. Soc. Japan **13**, 880 (1958).

I3. Crystal Field Splitting in $KNiF_3$. K. KNOX, R. G. SHULMAN, AND S. SUGANO, *Bell Telephone Laboratories, Inc.*—The cubic perovskite crystal $KNiF_3$ in which the Ni^{++} ion is surrounded by a regular octahedron of fluoride ions allows a direct comparison between crystal field theory and the optical absorption spectrum. We have measured the optical spectrum of a single crystal from 4000 cm^{-1} to 45 000 cm^{-1} in a Cary double-beam spectrometer from 300°K to 4.2°K. Seven bands and two lines were identified and shown to agree with the spectrum predicted[1] by assuming the crystal field splitting to be $10\,Dq = 7250$ cm^{-1}. At low temperatures the $^1\Gamma_3$ line splits into two lines at 15 800 cm^{-1} and 16 190 cm^{-1}. In $KNiF_3$ the bands shift to higher frequencies by several hundred wave numbers, going from 300°K to 77°K through T_N, whereas for paramagnetic $KMgF_3$: 5% Ni the shift is much smaller. With the ligand field functions determined by nuclear magnetic resonance experiments[2] it is possible to calculate[3] values of $10\,Dq$ and the other observed parameters. A comparison between theory and experiment will be presented.

[1] A. D. Liehr and C. J. Ballhausen, Ann. Physik **6**, 134 (1959).
[2] R. G. Shulman and K. Knox, Phys. Rev. Letters **4**, 603 (1960).
[3] Y. Tanabe and S. Sugano, J. Phys. Soc. Japan **11**, 864 (1956).

I4. Strain-Induced Splitting of a Chromium Fluorescence Line. A. PIKSIS, S. SUGANO, AND A. L. SCHAWLOW, *Bell Telephone Laboratories, Inc.*—In a purely cubic crystal field (as at a cubic site in MgO) the ^2E state of the Cr^{3+} ion has a two-fold orbital degeneracy and emits a single sharp fluorescence line. If the surrounding octahedron of oxygen ions is distorted, as in ruby, the degeneracy is removed, and two fluorescence lines are seen. We have applied pressure along [100], [110], and [111] directions in MgO crystals and observed the resulting line splittings. From the polarization, the sign of the field is obtained, and the trigonal field resulting from compression is is found to be positive. The nature of the splitting depends on the stress direction and, for a [111] stress, involves spin-orbit coupling. Theoretical estimates agree well with the observations. Although the fluorescence lines are quite sharp (~0.25 cm^{-1}), the line width is shown to be primarily caused by strain, and more perfect crystals could be expected to give considerably narrower lines.

I5. Effect of Isotopic Composition on Infrared Absorption of Solid Lithium Hydride. W. B. ZIMMERMAN AND D. J. MONTGOMERY, *Michigan State University.*—Infrared absorption spectra from 12.5 μ to 25 μ were obtained at room temperature for thin films of lithium hydride made from varying proportions of Li^6 and Li^7, H^1 and H^2. With suitable film thicknesses (0.03 μ–2 μ), distinct and reproducible absorption maxima were observed. For the isotopically pure compounds, a single absorption maximum was observed, the position shifting as the square root of the reduced mass. This behavior, in conformity with the predictions of the simple Born theory, has been observed in[1,2] Li^6F and Li^7F, and in[3] Li^7H^1 and Li^7H^2. For isotopically impure compounds in which the departure from purity is slight, or in which the isotopes differ only slightly in mass, the behavior cannot be differentiated from that expected for a single isotopic species of the average isotopic mass. But otherwise the behavior is complicated, the shape of the patterns changing and the shifts following no obvious rule.

* Supported by the U. S. Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.
[1] R. W. H. Stevenson and P. T. Nettley, Nature **182**, 472 (1958).
[2] D. J. Montgomery and R. H. Misho, Nature **183**, 103 (1959).
[3] W. B. Zimmerman and D. J. Montgomery, Phys. Rev. **120**, 405 (1960).

I6. Photon Absorption by Valence Electrons in Magnesium.* H. KROGER AND D. H. TOMBOULIAN, *Cornell University.*—A normal incidence vacuum spectrograph having a dispersion of 4.26 A/mm has been used to measure the photon absorption by magnesium in the spectral region extending from 230 A to 650 A. This region corresponds to photon energies in the 55-ev to 20-ev range. The resolution at the high-energy end is better than 0.1 ev. Measurements made on evaporated films (thickness 500 A to 4000 A) indicate that fine structure exists on the low-energy side of the L absorption edge. Such structure must be ascribed to photon absorption by valence electrons since the threshold energy corresponding to the $L_{2,3}$ edge is located at 49.5 ev. For magnesium, absorption maxima are found at the following photon energies expressed in ev: 21.7, 28.0, 31.7, 35.0, 38.7, 40.7, 44.5, and 46.7. These results will be compared with x-ray fine structure data and with recently published results on eigen loss measurements.[1]

* Supported by the Office of Ordnance Research U. S. Army.
[1] C. J. Powell and J. B. Swann, Phys. Rev. **116**, 81 (1959).

I7. Preparation of Unsupported Carbon Films and Their Absorption at 180 A.* D. J. BAKER, D. E. BEDO, AND D. H. TOMBOULIAN, *Cornell University.*—The search for foils suitable to serve as windows in the soft x-ray region suggested the use

of unsupported carbon films. Such films were prepared by depositing the material on a glass slide treated with a wetting agent. The carbon was vaporized from a high-current vacuum arc[1] operated intermittently between pure carbon electrodes one of which was pointed while the other was flat. The deposited layer was "floated off" by immersing the slide in distilled water. Unusually large unsupported films, with areas up to 1.6 cm^2, have been made by this process. Such films have a surface density of 48 $\mu g/cm^2$, and a corresponding thickness of 2000 A if a density of 2.4 g/cc is assumed. It is possible to make much thinner specimens, but the largest possible unsupported size decreases rapidly with diminishing thickness. The attenuation was measured by means of a photon counting spectrometer described previously.[2] The value of the linear absorption coefficient (at 180 A) depends somewhat on the age of the film and is found to approach the constant value of $(1.25\pm0.1)\times10^5$ cm^{-1}.

* Supported by the Office of Naval Research.
[1] G. Dearnaley, Rev. Sci. Instr. **31**, 197 (1960).
[2] D. E. Bedo and D. H. Tomboulian, Bull. Am. Phys. Soc. Ser. II, **4**, 419 (1959).

I8. Proposed Mechanism for Far Infrared Absorption in Ionic Crystals. K. Dransfeld and H. E. Bömmel, *Bell Telephone Laboratories, Inc.*—For low frequencies and high temperatures the far infrared absorption in ionic crystals may be considered as a relaxation process: The low-frequency electric field of the incident radiation leads to a shift of the vibrational energy states of the crystal, predominantly for phonons of very short wavelengths, thereby disturbing the thermodynamic equilibrium. In order to re-establish equilibrium the occupation numbers will rearrange themselves in a relaxation time τ, determined by phonon-phonon collisions. The absorption per cm of electromagnetic waves of frequency ω due to this relaxation process should vary as ω^2 at high temperatures ($\omega\tau<1$) as observed[1] for NaCl and KCl, and it should disappear at low temperatures ($\omega\tau>1$) consistent with absorption measurements for the same salts down to liquid air temperature.[2]

[1] Genzel *et al.*, Z. Physik **154**, 13 (1959).
[2] Hertz and Rubens, Naturwissenschaften **10**, 1057 (1922).

I9. Optical Absorption of Ni^{2+} and Co^{2+} in Cubic Symmetry. R. Pappalardo, D. L. Wood, and R. C. Linares, Jr., *Bell Telephone Laboratories, Inc.*—The optical absorption of Ni^{2+} and Co^{2+} has been studied in single crystals of MgO, ZnO, ZnS, Mg Al_2O_4, and yttrium gallium garnet at room temperature, 78°K and 4.2°K in the 2.5 μ to 0.2 μ region. In all these systems the crystal field acting on the impurity ion has predominantly cubic symmetry, while the coordination number can be four, six, or eight. In MgO crystals with low impurity level the usual intense intrasystem bands have been resolved into individual components, some of which are narrow lines, with half-width ~5 cm^{-1} at 4.2°K. Considerable fine structure was also found in the spectrum of the ZnO crystals, and its connection to spin-orbit coupling effects will be discussed. Finally, the spectra of Ni^{2+} and Co^{2+} in MgO and ZnO were used to infer the site symmetry of these ions in Mg Al_2O_4 and Yttrium Gallium Garnet.

I10. Optical Absorption Spectra of the First Transition Series Ions in CdS. R. E. Dietz and R. Pappalardo, *Bell Telephone Laboratories, Inc.*—Single crystals of CdS have been doped by diffusion with ions of the first transition series and the corresponding optical absorption studied in the 2.5 μ to 0.5 μ region at 300°K, 78°K, and 4.2°K. Absorptions showing considerable fine structure have been found for CdS:Ni and CdS:Co, while broad bands were found in crystals doped with Cu, V, Mn, and Cr. The absorptions of the crystals doped with N , Co, and Cu are consistent with the predictions of the crystal field theory for the corresponding divalent ions in tetrahedral coordination. The absorptions found experimentally for CdS:V, CdS:Cr, and CdS:Mn will be compared with predictions of the crystal field theory for the corresponding divalent and trivalent ions in tetrahedral coordination.

I11. Pressure Effects in Luminescence: Classical Estimates.* L. Reiffel, *Armour Research Foundation.*—The magnitudes of pressure effects on various characteristics of phosphors with temperature-dependent decay time are estimated using a classical, one-dimensional configurational coordinate approach. Effects considered include the already experimentally established pressure-induced changes in trap depth and absorption peak position as well as changes in bandwidth, fluorescence efficiency, and energy storage efficiency along with associated changes in decay time and light intensity. Large spectral shifts in either prompt or phosphorescent spectra which could arise from various band overlap effects or alterations in the populations of two communicating states also are considered. A classical approach to estimating pressure-induced effects is justified by the technical difficulty of low-temperature, high-pressure experiments. Preliminary results also will be given concerning the activation volumes associated with trap escape in mixed halide crystals such as NaBrI(Tl) as compared to single halide crystals such as NaI(Tl) and NaBr(Tl). Interpretation in terms of possible disruption of the synchronous breathing-mode motion of the anions surrounding substitutional Tl^+ will be suggested. This interpretation rests critically on the pressure dependence of cross-over probability between states which will be treated semiclassically.

* Work supported in part by U. S. Air Force Office of Scientific Research contract.

Friday Afternoon at 2:00

Eckhart 133

(A. C. G. Mitchell presiding)

Apparatus of Nuclear Physics

Invited Paper

J1. Polarization Measurements on Neutrons from the $Li^7(p,n)Be^7$ Reactions. S. E. Darden, *University of Notre Dame.* (30 min.)

Contributed Papers

J2. Fast-Neutron Detection and Spectroscopy Using a Solid State Detector. T. A. Love and R. B. Murray, *Oak Ridge National Laboratory.**—A neutron sensitive counter has been constructed by depositing a thin layer of Li^6F between two silicon surface-barrier counters. Neutrons are detected by observing the $\alpha+T$ charged particles resulting from the

$Li^6(n,\alpha)T$ reaction; pulses from the two counters are added and the sum pulse is amplified and recorded. Since the sandwich geometry permits simultaneous detection of both reaction products, the magnitude of the sum pulse is proportional to the energy of the incoming neutron plus the reaction Q value. Pulse-height spectra from slow neutrons and from monoenergetic fast neutrons, in the energy region 0.6 to 15 Mev, have been recorded from several counters of this type using sensitive areas of about 0.7 cm^2, with a Li^6F layer of order 150 $\mu g/cm^2$ thick. In all cases a well-defined neutron peak was observed in the pulse-height spectra. The full width at half-maximum of the fast-neutron peak was about 300 kev approximately independent of neutron energy.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

J3. Directional Counter for Fast Neutrons.* ROBERT C. AXTMANN, GERARD M. LEBRETON, AND ARTHUR L. DELERAY, *Princeton University.*—Fast neutron detectors were assembled that had excellent directional properties, negligible gamma response, and fast response times. The counters were 2-in. cubes of alternate thin (0.35–1.0 mm) layers of plastic scintillator and fat (¼-in.) layers of ordinary plate glass. The assemblies were viewed edge-on by a photomultiplier tube with a 2-in. photocathode. When the layers were oriented parallel to the direction of a neutron beam, the count rate from the highest energy knock-on protons was maximum. Maximum neutron energy is transferred in head-on collisions, and such collisions resulted in maximum energy transfer to the scintillator rather than to the inert glass. The direction of a collimated beam of 14-Mev neutrons was determined to better than 5° with the detector biased at approximately 10-Mev proton energy. Counters whose plastic components were made from either thin sheets or rows of filaments[1] had essentially equivalent properties.

* Supported by grants-in-aid from the Socony Mobil Oil Company and the Union Carbide Nuclear Company.
[1] G. T. Reynolds and P. E. Condon, Rev. Sci. Instr. **28**, 1098 (1957).

J4. Analysis of Gamma-Ray Pulse Height Spectra Using Least-Mean-Square Fitting Techniques.* J. I. TROMBKA AND M. L. WIEDENBECK, *The University of Michigan.*—A method for determining the energies and intensities of gamma rays from the measurement of the pulse-height spectrum using a NaI(Tl) scintillation crystal detector has been developed. The polyenergetic gamma pulse-height spectrum is synthesized by using a series of monoenergetic pulse-height distributions characteristic of the various monoenergetic components in the incident beam. The contribution of each of the monoenergetic components to the pulse-height spectrum is determined using least-mean-square fitting techniques. From a knowledge of the contributions of each monoenergetic component and the crystal effciency for each given energy, the intensities and energies of the gamma rays in the incident beam are determined. Experimental results will be presented.

* Supported in part by the Michigan Memorial-Phoenix Project and by the U. S. Atomic Energy Commission.

J5. Intrinsic Line Broadening in NaI(Tl) Gamma-Ray Spectrometers. C. D. ZERBY, A. MEYER, AND R. B. MURRAY, *Oak Ridge National Laboratory.**—Previous studies of the resolution of NaI(Tl) gamma-ray spectrometers have indicated the existence of an intrinsic line-broadening associated with the properties of the crystal itself. It is the purpose of this paper to show that the observed nonlinear response of NaI(Tl) to gamma rays[1] (hence to electrons) contributes to the intrinsic line-broadening. The work reported here is based on a Monte Carlo code previously formulated to calculate pulse-height spectra resulting from monoenergetic gammas on NaI(Tl) crystals of various sizes and geometries. This code has been altered to include the nonlinear response of NaI(Tl) to electrons, an energy-dependent function determined from experimental work with gammas. Results of the calculations, applied to a 2½-in. diam by 2-in. high crystal, indicate a distinct broadening in the full-energy peak resulting from photon-electron cascades. The calculated fractional line width (f.w.h.m.) is negligible for low energies and amounts to 2.7% at 0.15 Mev, 5.3% at 0.5 Mev, and 1.5% at 2.5 Mev. The dependence of this effect on crystal size and geometry will be discussed.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] See C. E. Crouthamel, *Applied Gamma-Ray Spectrometry* (Pergamon Press, New York, Chap. 2.

J6. Scintillation Response of CsI(Tl) to Gamma Rays. R. B. MURRAY AND R. GWIN, *Oak Ridge National Laboratory.**—Studies of the scintillation response of NaI(Tl) to gamma rays at other laboratories (see preceding abstract) have indicated a distinct nonlinearity in the pulse height vs energy. This paper reports a search for a similar effect in CsI(Tl). The basis of the present work is a measurement of pulse height per unit energy for gamma rays in the energy region 10 kev to 3 Mev. The magnitude of the pulse height L associated with a gamma ray of energy E is measured with reference to a pulse generator whose output is monitored with a precision laboratory potentiometer. The experimental procedure thus does not involve knowledge of the linearity or zero of the electronic system. Results on two CsI(Tl) crystals indicate a nonlinearity in pulse height vs energy similar to that of NaI(Tl). A plot of L/E vs E, normalized to unity at 662 kev, passes through a maximum in the 50-kev region with a peak value of about 1.12. This behavior can be interpreted in terms of a theoretical model of the scintillation process in activated inorganic crystals.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

J7. Alkali Halide Luminescence at Low Temperatures. H. V. WATTS, L. REIFFEL, AND M. D. OESTREICH, *Armour Research Foundation.*—The luminescence properties of twelve pure (unactivated) alkali halides have been studied for α-particle and γ-ray excitation over the temperature range 4°K–300°K. LiI, KI, and CsI exhibit a constant luminescence pulse height and decay time at temperatures below 80°K. NaI exhibits a maximum in pulse height at 60°K similar to that reported previously by Van Sciver.[1] A second CsI sample shows both a low-temperature luminescence component and a room-temperature component similar to that induced by overheating as in the experiments of Knoepfel *et al.*[2] RbI shows two regions of linearly decreasing pulse height as temperature increases. The luminescence pulse heights of the iodides are comparable to that observed from thallium-activated sodium iodide, and the decay times are of the order of 0.1 to 2 μsec. CsBr, KCl, and NaCl luminesce at low temperatures, but with a much lower intensity than the iodides. LiF, NaF, KCl, and RbBr exhibit no detectable luminescence over the entire temperature range studied. The temperature dependence of pulse heights and decay constants is the same for both γ- and α-excited emission. Analysis of the luminescence pulse shape and the temperature dependence gives an indication of the number of luminescence components and the mode of decay of the excited luminescence centers.

[1] W. J. Van Sciver and L. Bogard, IRE Trans. on Nuclear Sci. **NS-5**, 90 (1958).
[2] H. Knoepfel, E. Loepfe, and P. Stoll, Helv. Phys. Acta **30**, 522 (1957).

J8. Atmospheric Pressure Windowless Deuterium Target.* R. A. LUX, I. MICHAEL, D. G. MCDONALD, AND W. HAEBERLI, *University of Wisconsin.*—An atmospheric pressure windowless deuterium gas target with a 2.5-mm beam aperture has been built. The system consists of a target chamber, open to atmospheric air through a series of apertures, and a differential

pumping column. The target chamber is 8 cm in diameter and 11 cm high. The beam enters through a tube 1 cm in diameter and 3 cm long which is divided into seven volumes by apertures. Helium is fed into the fourth volume at a rate of 30 liters/hr. The tube is separated from the pumping column by a 0.2-cm air gap. The first three stages are pumped on by mechanical pumps of displacements 14.4 liters/sec, 7.2 liters/sec, and 7.2 liters/sec, respectively. The fourth stage is a Roots blower of 40 liters/sec, and the last two are diffusion pumps of 20 liters/sec each. The pressure in the last stage is 4×10^{-5} mm. The energy loss to the center of the target chamber for 2.2-Mev protons is 275 kev, corresponding to 9.0 cm of D_2. The actual path length in D_2 and He is 7.0 cm, the remaining energy loss being due to air. When the target is not flushed, the contamination increases by approximately 1% per hour. About 75% (by volume) of this is He, the remainder is air. A deuterium flow of 0.1 liter/hr into the target is sufficient to maintain the purity above 98%.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

J9. Neutron Diffraction Studies with Image Intensifiers. J. F. LEMKE AND L. REIFFEL, *Armour Research Foundation.*—Various methods of recording neutron diffraction patterns using imaging rather than point-by-point detectors are under investigation in this laboratory. Large savings in time can result if all points in the diffracted neutron field are under observation simultaneously. Intensifier screen techniques using luminescent materials in fiber or sheet form in conjunction with electronic or photographic recording are being considered, although work has proceeded furthest on a neutron-sensitive spark counter method.[1] Our new large spark counter image intensifier uses an enriched B^{10} converter and consists of staggered planar arrays of 164 cathode wires and 165 anode wires which provide a sensitive area of 1870 cm². The large size of the sensitive area and the relatively close spacing of the wires (~1 mm) permits an adequate number of picture elements in the pattern which is recorded by taking a time exposure of the spark distribution on 4-in.×5-in. film. Line structure in the recorded image is eliminated by moving the counter relative to the film and neutron beam during exposure. Single crystal Laue patterns are obtainable in ~10 min using a 1-cm² unstepped collimator at a flux of $\sim10^{11}$ nv. The system is now being converted for powder-pattern work. Comparison with other imaging methods under investigation will be given.

[1] L. Reiffel, Rev. Sci. Instr. 29, 1151 (1958).

J10. Study of Focusing Electrodes.* AKIHIKO YOKOSAWA, *Argonne National Laboratory.*—The dynamics of protons in several focusing electrodes is investigated, taking account of space charge. It seems inadequate to apply the paraxial theory to the electrostatic lens, especially for a high-intensity beam. In this analysis the equation for nonparaxial rays is used. It was found that values of potential, radial, and axial fields obtained from the electrolytic plotting tank were not accurate enough for the calculation of beam trajectories. Therefore, these values were computed at each of the mesh points with the aid of an IBM 704 computer. The uniform charge distribution was assumed. The aberrations with respect to the beam current and the geometry of electrodes are investigated. The acceptance of the lens is also computed. The foregoing analysis was done to design a preaccelerating electrode to be used with the 50-Mev linear accelerator for the Argonne Zero-Gradient Synchrotron.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Social Sciences 122

(S. MROZOWSKI presiding)

Electron Paramagnetic Resonance

K1. Paramagnetic Resonance of NO in KCl.* C. JACCARD, *Argonne National Laboratory.*—Crystals of KCl doped in the melt with KNO_2 or KNO_3 and irradiated with x rays at room temperature show in EPR many different paramagnetic centers. One of these, a triplet, is strongly anisotropic up to room temperature, where it decays in half an hour. The principal axis (z) of the g and *HFS* tensors is in the [100] direction, and the x- and y-axes in [011] and [0$\bar{1}$1]. The g values are $g_x=2.0038\pm0.0002$, $g_z=2.0070\pm0.0004$, $g_y=2.0097\pm0.0004$, and the *HFS* parameters at -50°C are $A=30.9\pm0.2$, $B=7.0\pm0.3$, and $C=5.0\pm0.3$ gauss. The relative concentration of this center is enhanced in a pure crystal heated at 700°C for two days in a flow of NO gas, and the bleaching of F centers increases markedly the ERP signal intensity. One of the models considered is an NO^+ (in a positive ion vacancy) which has trapped an electron during irradiation to become an NO molecule. Although the vacancy volume would allow the center to rotate, it must be bound with a neighboring chlorine ion to give the anisotropy.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

K2. Ferrimagnetic Resonance Field of Terbium Doped Yttrium Iron Garnet. L. R. WALKER, *Bell Telephone Laboratories, Inc.*—Dillon and Nielsen[1] found that if small amounts, of the order of 0.1% or less, of the yttrium ions in yttrium iron garnet were replaced by terbium, the field for resonance at liquid helium temperatures showed a very strong dependence upon dc field direction. Kittel[2] suggested that if the lowest pair of energy levels of the terbium ions approached closely for particular dc field directions large excursions of the resonance field would occur. The resonance field has been calculated here by actually evaluating the rf susceptibility and dc magnetization of the terbium from its energy levels and wave functions. To evaluate these a plausible spin Hamiltonian, containing three adjustable parameters, for a terbium ion on a dodecahedral site of the host lattice was used, utilizing the point charge potential of the oxygen neighbors as a guide. A quite satisfactory quantitative fit with the observed fields is obtained which appears to be insensitive to substantial changes in some of the crystal field parameters.

[1] J. F. Dillon, Jr., and J. W. Nielsen, Phys. Rev. Letters 3, 30 (1959).
[2] C. Kittel, Phys. Rev. Letters 3, 169 (1959).

K3. New Method for Paramagnetic Relaxation Time Measurements.* J. A. GIORDMAINE, *Columbia University.*—Relaxation times T_1 have been measured by a method in which microwave saturating power is amplitude-modulated at an

audio frequency ω. The phase difference ϕ between the power modulation and the resulting modulation of a reflected signal proportional to the imaginary part of the susceptibility is measured as a function of ω. For a single relaxation time $\tan\phi$ has a maximum value of $2WT_1(1-4W^2T_1^2)^{-\frac{1}{2}}$ occurring when ω is $(1/T_1)(1-4W^2T_1^2)^{\frac{1}{2}}$. W is the rf-induced transition probability. From the frequency and magnitude of the maximum phase difference, T_1 is obtained at a particular spin temperature. This method, which involves only measurements of audio frequency and phase, is convenient and appears to be capable of higher precision than other microwave methods. It is particularly sensitive to distributions of T_1. Results are reported for Cr^{+3} impurities in ruby at 78°K where both single and multiple relaxation times are observed for various transitions at X band.

* Work supported jointly by the Signal Corps, the Office of Nava Research, and the U. S. Air Force Office of Scientific Research.

K4. Radiation Induced Paramagnetic Defects in Potassium Azide. D. MERGERIAN AND S. A. MARSHALL, *Armour Research Foundation.*—Electron paramagnetic resonance absorption has been observed in single crystals of potassium azide irradiated by a 50-kv x-ray source at room temperature. These crystals take on a deep brown coloration and exhibit a magnetic resonance absorption in the neighborhood of $g=2$ which consists of from 12 to 14 lines. Of these, 6 lines are from 5 to 10 times more intense than the remainder and appear to form two distinct groups of 3 lines each which saturate at different rates. One of the groups of 3 lines further shows a hyperfine structure consisting of at least 7 lines with line widths of approximately 1 oe. Each group of 3 lines is attributed to a separate defect center; this hypothesis is further supported on the basis of the two optical absorption bands observed in similarly colored crystals by Tompkins and Young.[1] Orientation studies and saturation effects observed at 77°K on each of the 3 line groups also are presented.

[1] F. C. Tompkins and D. A. Young, Proc. Roy. Soc. (London) **A236**, 10 (1956).

K5. Line Width Variations in the Magnetic Spectrum of Divalent Nickel in Sapphire.* T. T. KIKUCHI, S. A. MARSHALL, AND A. R. REINBERG, *Armour Research Foundation.*—Observations made on the paramagnetic resonance absorption of divalent nickel in sapphire show a strong line width dependence upon crystal orientation. Line widths, taken at boiling nitrogen temperature and under conditions of negligible saturation, were measured at intervals of 5 deg of arc from the parallel to the perpendicular orientations. It is found that for the $E_2 \leftrightarrow E_2$ transition, the line width between points of inflection varies from 8.6 oe at $\theta=5°$ to 34 oe at $\theta=90°$ with a maximum of 52 oe at $\theta=75°$. An analysis of the resonance Zeeman field strength vs crystal orientation for this transition indicates that the line width variation can be correlated to a distribution of randomly oriented crystallites. On the basis of the magnetic resonance line widths, the half-width of mosaic distribution is estimated at 0.14 deg of arc.

* Supported by U. S. Air Force Cambridge Research Center.

K6. Trapped Radicals in Organic Deposits.* R. MANGIARACINA AND S. MROZOWSKI, *University of Buffalo.*—Polymeric deposits showing a paramagnetic absorption were made by passing an electrical discharge through vapors of relatively simple organic compounds. Very high-spin concentrations (10^{20} per gram) were obtained in films formed using naphthalene vapor ($C_{10}H_8$), the absorption having a line width of 9 gauss. The nature of the deposited films varies with the distance from the electrodes, the color changing from dark brown to yellow and the spin absorption decreasing as the distance increases. To check whether these spin centers are related to the centers formed when organic substances are charred, such films were heat treated to various temperatures. It was found that above 200°C, as the heat-treatment temperature increases, the spin concentration rapidly diminishes, reaching a minimum at around 400°C. Above 400°C a strong absorption develops (maximum at around 650°C) which shows all the features of the absorption observed in chars. Thus there seems to be no relation between the molecular type radicals present in such polymers and the spin centers in chars, as suspected.[1] Further work on these polymers including studies of infrared and ultraviolet absorption is in progress.

* Work supported by the Office of Naval Research.
[1] S. Mrozowski and D. Wobschall, J. chim. phys. (to be published).

K7. Formation of Spin Centers in Carbons by Chemical Attack.* K. ANTONOWICZ,† *University of Buffalo* (introduced by S. Mrozowski).—It was found that high concentration of electron spin centers can be obtained in carbon originally heat treated at tempeatures 1000–2400°C by reheating them to around 1000°C in an oxidizing (oxygen, sulfur) or reducing (hydrogen) atmosphere. The free spins were detected at room temperature using a paramagnetic spin resonance spectrometer. The intensity, width, and shape of the absorption line depend on the pressure of the gas, duration and temperature of the reheat, as well as the whole previous history of the carbon sample. Observed width varied from 25 to 0.9 gauss, with the shape varying from Lorenzian for narrow to Gaussian-like for broad lines. Unsymmetrical lines were obtained under special conditions, becoming symmetrical upon further treatment. All spin centers are destroyed by heating the sample to above 1000°C in vacuum. In some cases a strong reversible broadening by oxygen atmosphere was found, the oxygen sensitivity depending on the conditions of preparation. These and other facts found in this work indicate that the spin centers are created by chemical attack at the boundaries of carbon crystallites and are essentially similar to those observed in chars.

* Work supported by the Office of Naval Research
† On sabbatical leave from the Nicolous Copernicus University, Torun, Poland.

K8. Electron Paramagnetic Resonance of Color Centers in Bleached Additively Colored KCl. GORDON A. NOBLE AND JORDAN J. MARKHAM, *Physics Division, Armour Research Foundation.*—As potassium chloride crystals containing an excess of potassium are irradiated with light at 300°K, the peak and width of the absorption in the F region changes and the M, R_1, R_2, and N bands appear. We have observed the electron paramagnetic resonance in the equilibrium state where there is very little change upon further illumination. The g factor does not change from the value 1.9964 ± 0.0005. However, the width at maximum slope decreases from 47 to 34 gauss. Both these quantities remain isotropic. The magnetic resonance relaxation time of the new center is much shorter than that of the F center. At 78°K the saturation data do not fit Portis's equation for an inhomogeneously broadened line. At 4°K one portion of the absorption does not saturate and recover independently of the rest. The shape corresponds to only one Gaussian line at all power levels. These observations indicate that all the F centers are removed by the bleaching process and that the remaining optical absorption in the F region represents entirely new centers. These centers also may be responsible for the other absorption bands. These experiments will be discussed, considering the model for the M, N, and R centers based upon association of F centers.

K9. Spin Echo Experiments in Cerium and Erbium Doped Calcium Tungstate. W. B. MIMS AND K. NASSAU, *Bell Telephone Laboratories, Inc.*—Electron spin echos have been observed in samples of $Ce/CaWO_4$ and $Er/CaWO_4$ having magnetic concentrations $\sim10^{-4}$ rare earth : calcium ratio. Echo decay envelopes show phase memory times up to 50 μsec, from

which it appears that T_2 (in the Bloch equations) is long and that the lines are inhomogeneous. Studies have been made of the effect of varying concentration, "g" factor, and temperature in the 1.8°K to 4.2°K range. No appreciable temperature dependence was observed for cerium, whose lattice times are long, but a strong dependence was seen in the case of erbium when the lattice time fell below 1 msec. In a mixed Ce/Er/$CaWO_4$ sample the cerium echo times were limited by eribum relaxation. Echo memory times give an indication of the rate of change of local magnetic fields within the material and point to some of the factors which control the rate of cross relaxation within a paramagnetic resonance line.

FRIDAY AFTERNOON AT 2:00

Rosenwald 2

(CYRIL SMITH presiding)

Lattice and Structures

L1. Activation Volume for Self-Diffusion in Lithium.* R. A. HULTSCH, R. D. ENGARDT, AND R. G. BARNES, *Iowa State University.*—Nuclear magnetic resonance spin-echo techniques have been used to obtain the pressure dependence to 7000 atm of $(T_2')_d$, the phase memory time associated with the nuclear dipole-dipole interaction, in lithium metal. At temperatures at which the nuclear magnetic resonance line width is narrowed by self-diffusion, the effect of pressure is to decrease diffusion and hence $(T_2')_d$.[1] The measurements were made at a frequency of 10 Mc/sec, and over the pressure range used, $\ln(T_2')_d$ is found to be proportional to pressure. The activation volume V_{act} was obtained from the pressure dependence of $\ln(T_2')_d$ at 37°, 50°, 71°, and 78°C. Within the accuracy of the measurements, V_{act} is temperature independent with the value 3.4 ± 0.3 cm³. Although this is only 26% of the molar volume, it agrees well with the value 25% based on the dynamical theory of diffusion.[2]

* This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

[1] R. G. Barnes, R. D. Engardt, and R. A. Hultsch, Phys. Rev. Letters **2**, 202 (1959).

[2] S. A. Rice and N. H. Nachtrieb, J. Chem. Phys. **31**, 139 (1959).

L2. Theory of the Bordoni Peak. A. D. BRAILSFORD, *Ford Motor Scientific Laboratory.*—A new model of dislocation motion is proposed. The response of a dislocation to an applied stress is described in terms of a redistribution of kinks along its length. In contrast with previous models,[1,2] in which a kink is visualized as a smooth step extending over many lattice constants, we suppose a kink to be abrupt. Consequently, kink diffusion is considered to be a thermally activated process. Transport equations are formulated which include generation, diffusion, and collision of kinks. Solution of these equations for small applied stress leads naturally to a theory of the Bordoni anelastic peak. The characteristic relaxation time depends on the line length as well as on the attempt frequency and activation energy for kink diffusion. With an exponential distribution of line lengths, and no additional assumptions or arbitrary parameters, the theory accounts *quantitatively* for (1) the large peak half-width in pure cold-worked metals and (2) the decrease in peak-height and slight lowering of the temperature of maximum decrement with alloying. The absence of a Bordoni peak in well-annealed metals is explained if the dislocations are then arranged parallel to close-packed directions, thereby all but eliminating the kink density.

[1] A. Seeger, Phil. Mag. **1**, 651 (1955).

[2] J. Lothe and J. P. Hirth, Phys. Rev. **115**, 543 (1959).

L3. Reactor Irradiation of PbTe, Bi_2Te_3, and ZnSb. R. T. FROST, J. C. CORELLI, AND M. BALICKI, *Knolls Atomic Power Laboratory.**—Instrumented samples of polycrystalline n-type PbTe and Bi_2Te_3 and p-type ZnSb have been irradiated in the Engineering Test Reactor (ETR) to a total integrated flux-time of $1.2 \cdot 10^{20}$ cm^{-2} of neutrons having energies greater than 1 Mev. The corresponding thermal flux time was $6.1 \cdot 10^{20}$ cm^{-2}. Electrical resistivity and Seebeck coefficient were monitored by means of seven leads attached to each of the three samples, which were located within a cylindrical region in the reactor $\frac{1}{2}$ in. long and $\frac{3}{4}$ in. in diameter. Thermal and resonance neutron reactions on tellurium produced iodine approaching the amount used in the initial doping of the n-type materials. Gamma-ray spectroscopy on uninstrumented samples irradiated to comparable flux-times failed to disclose lines due to long-lived daughters of fast neutron-induced reactions. The changes in electrical properties of uninstrumented PbTe and Bi_2Te_3 samples induced by a fast (>1-Mev) neutron flux time of $1.5 \cdot 10^{19}$ cm^{-2} are essentially completely annealed in the range of temperature from 170° to 190°C, respectively.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

L4. Changes in the Thermoelectric Properties of PbTe, Bi_2Te_3 and ZnSb During Irradiation. J. C. CORELLI AND R. T. FROST, *Knolls Atomic Power Laboratory.**—The instrumented in-pile experiment described in the preceding paper has yielded the following changes. The Seebeck coefficient of the n-type Bi_2Te_3 sample increased by ≈10% during the irradiation while the resistivity was increased by a factor of ~2.8 with no significant changes for fast (>1-Mev) flux times greater than 5×10^{19} n/cm². In the case of p-type ZnSb the resistivity increased by a factor of ~12 with no large changes resulting beyond a fast flux time of 6×10^{19} n/cm². The p-type ZnSb converted to n-type after an accumulated fast flux time of $\sim 1.6 \times 10^{17}$ n/cm², and thereafter its Seebeck coefficient exhibited a gradual increase of ≈15% with increased in-pile time. The resistivity of n-type PbTe increased by a factor of ~25 after a total accumulated fast flux-time of 1.2×10^{20} n/cm² with no large changes observed for fast flux-times greater than $\sim 6 \times 10^{19}$ n/cm². Auxiliary experiments suggest that a significant part of resistivity increases for all samples because of stress-induced damage during reactor power transients. In some cases temperatures during irradiation were near the annealing threshold for PbTe and Bi_2Te_3.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

L5. Monte Carlo Computations on the Ising Model: The Body-Centered Cubic Lattice. LESTER GUTTMAN,* *General Electric Research Laboratory.*—The Monte Carlo method of computation has been used to obtain some equilibrium properties of body-centered cubic binary solid solutions whose atoms interact according to the Ising model. Four cases have been treated: (a) $N=128$, $c=\frac{1}{2}$, (b) $N=1024$, $c=\frac{1}{2}$, (c) $N=1024$, $c=\frac{3}{4}$, and (d) $N=1024$, $c=\frac{1}{8}$ (N being the total number of atoms and c the fraction of one kind. In all cases the heat capacity has a well-defined maximum. At the equiatomic composition, the height of this maximum is greater in the larger crystal. Discontinuities in thermodynamic properties were not observed, and it seems reasonable that the order-disorder transition in an infinite crystal would be characterized by an infinite heat capacity, as calculated by Onsager and others for two-dimensional crystals. Comparison of the results with experimental properties of β-CuZn suggests a remarkable

applicability of the Ising model to this system. The potentialities and limitations of the Monte Carlo method for systems with phase transitions are discussed.

* Present address: Solid State Science Division, Argonne National Laboratory.

L6. Dielectric Breakdown Dendrites on LiF Cleavage Faces. J. PASTERNAK AND J. W. DAVISSON, *U. S. Naval Research Laboratory.*—A technique of short-time etching, or flash etching, has been used to investigate the nature of surface dielectric breakdown paths on cleavage faces of LiF crystals. It was observed that all the ⟨100⟩ paths, some of the ⟨110⟩ branches, and the scratches which were caused by rubbing with soft tissue paper appeared on the first flash etch while more etching was required to reveal dislocation etch pits which accompanied plastic deformation. Other samples which were annealed after breakdown and rubbing also showed ⟨100⟩ paths and scratches following the first flash etch without showing any of the aged dislocations. When the dislocation etch pits did appear on the unannealed samples, it was observed that ⟨110⟩ branches which consisted of double rows of dislocation-type etch pits were revealed on the ends of the ⟨100⟩ dendrites. It is suggested that the ⟨100⟩ dendrites are formed by electronic currents which caused local melting on the surface.

L7. Deep Etch Study of Dielectric Breakdown Dendrites on LiF Cleavage Faces. J. W. DAVISSON, J. PASTERNAK, AND W. H. VAUGHAN, *U. S. Naval Research Laboratory.*—Deep etch studies of dielectric breakdown dendrites having ⟨100⟩ stems and arms with terminating ⟨110⟩ Y branches formed on LiF cleavage faces show that the Y branches disappear first and the dendrite stems last. The two parallel rows of etch pits constituting a branch of a Y converge as etching proceeds and terminate on a surface parallel ⟨110⟩ line. The deepest portion of the arms is the apex of the Y's. Double rows of steep conical etch pits paralleling the ⟨100⟩ stems are the last features to disappear. Since conical pits are not characteristic of new dislocations (square based pits are also observed), they may be following hollow ⟨110⟩ breakdown channels. The basic structure of the dendrite is observed at "Random Sites" which etch at the same rate as the dendrites. Each Site yields a giant etch pit showing four centers corresponding to steep ⟨110⟩ breakdown paths and also yields Y branches formed from submerged, surface parallel, ⟨110⟩ breakdown paths.

L8. New Method of Determining the Mosaic Structure of Crystals. ROBERT H. BRAGG, *Armour Research Foundation,* AND LEONID V. AZAROFF, *Illinois Institute of Technology.*—The integrated intensity of reflections from mosaic crystals depends upon the crystallite tilt parameter η and the mean crystallite size t_0.[1] In the new method the analysis depends upon variation of the coefficient of reflection Q and the primary extinction function $f(A_0)$ by varying the wavelength of the diffracted x rays λ. This variation is achieved by orienting the crystal so that a selected set of lattice planes of spacing d is inclined at angle θ relative to the direct beam which causes the desired wavelength to be reflected in accordance with Bragg's law. In order to place the intensities on an absolute basis, the intensity distribution in the incident beam $I_0(\lambda)$ is measured with a scintillation counter. Measurements have been made on a (111) plate of silicon using x-ray wavelengths in the range 0.37 to 1.18 A. Etch pit counts at the edge and center portions of the plate were 3×10^6 and 5×10^5/cm², respectively. Corresponding crystallite sizes were found to be 9 and 3 μ, and the corresponding tilt parameters were 15 and 3 sec of arc. The latter results were in satisfactory agreement with direct measurements using the focusing Laue case method of Guinier and Tennevin.[2]

[1] W. H. Zachariasen, *Theory of X-Ray Diffraction in Crystals* (John Wiley & Sons, Inc., New York, 1945).
[2] A. Guinier and J. Tennevin, Acta Cryst. **2**, 133 (1949).

L9. Lattice Dynamics of Alpha Uranium. D. O. VAN OSTENBURG, *Argonne National Laboratory.*—The structure of alpha uranium can be described as a close-packed hexagonal lattice that has been distorted to orthorhombic symmetry. If we choose any particular atom as origin, it has two nearest, two second nearest, four third nearest, and four fourth nearest neighbors. By following the method developed by Born and Begbie,[1] and later modified by Huang,[2] equations are developed which give the macroscopic elastic constants in terms of linear combinations of the microscopic force constants. Interactions out to fourth nearest neighbors are included. Through symmetry considerations, nineteen atomic force constants enter into force system with a total of fourteen relations between them. If measured values[3] of the nine elastic constants of alpha uranium are used, two sets of force constants are evaluated. One set is evaluated by including first, second, and third nearest neighbors while the other set is evaluated under the assumption of central forces between all twelve neighbors.

[1] G. H. Begbie and M. Born, Proc. Roy. Soc. (London) **A188**, 179 (1947); G. H. Begbie, *ibid.* **A188**, 189 (1947).
[2] K. Huang, Proc. Roy. Soc. (London) **A203**, 178 (1950).
[3] E. S. Fisher and H. J. McSkimin, J. Appl. Phys. **29**, 1473 (1958).

L10. Elastic Constants of YIG. N. G. EINSPRUCH AND T. E. HARTMAN, *Texas Instruments Incorporated.*—An ultrasonic pulse-echo technique has been used to measure propagation velocities of 10 Mc/sec compressional and shear waves in polycrystalline yttrium iron garnet. Results of the measurements (in units of 10^5 cm/sec) are: $v_c=7.01$, $v_s=3.87$. The Young's and shear moduli for YIG (in units of 10^{11} d/cm²) are: $E=\rho v_c^2=24.7$, $\mu=\rho v_s^2=7.53$, where ρ is the density of the material.

FRIDAY EVENING AT 6:30

Quadrangle Club

Banquet of The American Physical Society

SATURDAY MORNING AT 9:30

Mandel Hall

(M. HAMERMESH presiding)

Invited Papers on the Mössbauer Effect

M1. Study of Internal Magnetic Fields in Iron and Tin Alloys. S. S. HANNA, *Argonne National Laboratory.* (30 min.)

M2. Mössbauer Effect at High and Low Temperatures. D. NAGLE, *Los Alamos Scientific Laboratory.* (30 min.)

M3. Mössbauer Effect in Magnetic Materials. G. K. WERTHEIM, *Bell Telephone Laboratories, Inc.* (30 min.)

M4. Internal Conversion from Resonance Absorption. H. FRAUENFELDER, *University of Illinois.* (30 min.)

SATURDAY MORNING AT 9:30

Kent 106

(J. SIMPSON presiding)

Invited Papers on Cosmic-Ray Physics

N1. Production of Rare Gases in Meteorites as a Result of Cosmic-Ray Bombardment. A. O. C. NIER, *University of Minnesota.* (30 min.)

N2. Cosmic-Ray Interactions in Meteorites. ANTHONY TURKEVICH, *University of Chicago.* (30 min.)

N3. Cosmic-Ray Experiments with Nuclear Emulsions. M. W. FRIEDLANDER, *Washington University.* (30 min.)

N4. Cosmic-Ray Experiments at Large Distances from the Earth. PETER MEYER, *University of Chicago.* (30 min.)

SATURDAY MORNING AT 9:30

Breasted Hall, The Oriental Institute

(A. W. LAWSON presiding)

Solid-State Physics

O1. Phonon Scattering by Chemical Impurities in NaCl.* MILES V. KLEIN, *Cornell University.*—The thermal conductivity of NaCl crystals from several sources varied by as much as two orders of magnitude on the low-temperature side of the maximum at ~10°K, the conductivity of air-grown crystals (Harshaw) being particularly low. A semiquantitative correlation was found between the low-temperature thermal resistivity and the ultraviolet oxygen absorption band at 185 mμ. Both the resistivity and the absorption could be removed by high-temperature treatment in Cl_2 vapor. The original data could be reproduced by subsequent doping in the melt with NaOH. To reproduce Harshaw, 10^{-3} mole fraction melt-doping was necessary. In another series of experiments the effect of precipitation of Mn^{++} on phonon scattering in OH^--free NaCl was studied by measuring the conductivity of quenched crystals containing 10^{-4} mole fraction $MnCl_2$. Kinetics of the room-temperature precipitation were measured by means of electron spin resonance. Most of the ions clustered during the first 12 hr; the rest clustered slowly over a period of several days. The accompanying changes in the thermal conductivity were surprisingly small and first appeared during the second precipitation stage.

* Supported in part by the National Science Foundation and the U. S. Atomic Energy Commission.

O2. Theory of Lattice Thermal Conductivity at Low Temperatures. P. G. KLEMENS, *Westinghouse Research Laboratories.*—In the theory of the low-temperature lattice thermal conductivity one must solve an integral equation for the phonon distribution, describing the combined effect of processes conserving the phonon momentum (three-phonon N-processes) and processes tending to obliterate excess momentum. Various approximations have been proposed; these will be discussed and intercompared, with particular reference to the approximation of Callaway.[1]

[1] J. Callaway, Phys. Rev. 113, 1046 (1959).

O3. Classical Energy Transport in Disordered Lattices. ROBERT J. RUBIN, *National Bureau of Standards.*—For a simple cubic lattice consisting of an arbitrary distribution of two kinds of isotopes, the following initial value problem is solved. At time $t=0$, in a region R of the lattice, the velocities and positions of the atoms are canonically distributed at a temperature T: the rest of the lattice is at absolute zero. What is the mean square dispersion $\langle\sigma^2\rangle$ of the velocity of lattice particle A in R as a function of time if at $t=0$ energy is allowed to move freely out of R? The solution is obtained by generalizing a method used recently by the author.[1] The dispersion $\langle\sigma^2\rangle$ at time t is equal to the energy which resides in region R at time t for the special initial state in which all lattice particles are at their equilibrium positions and all particles are at rest except A whose velocity is the rms value for the temperature T. The application of this result in a computing machine experiment will be discussed.

[1] R. J. Rubin, J. Math. Phys. 1, 309 (1960).

O4. Volume Changes and Color Centers Produced by X Rays in NaCl at Low Temperatures.* S. MASCARENHAS† AND D. A. WIEGAND, *Carnegie Institute of Technology,* AND R. SMOLUCHOWSKI, *Princeton University.*—Volume expansion of x-ray irradiated NaCl was measured in the range 15°–90°K. Optical behavior was analyzed from 15° to 300°K. An improved photoelastic method was used, and strain profiles thus obtained agree with the shape predicted by the linear theory. Slow cooling (10°C per hr) is essential to minimize background strain. Twenty-four hours of irradiation by 45 kv, 30 mA x rays at 15°K produces $\Delta V/V$ of the order of 10^{-5}. This volume increase does not anneal up to 80°K. In contrast, the F band shows in this range three stages of annealing and three more between 80°K and 300°K. Growth curves of the F band and of the 343 mμ band were made at 15°K. Annealing at 80°K followed by re-irradiation at 15°K indicates that these bands recover quickly. Comparison with results on KCl and KBr indicate that the F centers are annihilated by hole capture. It follows also that in the range 15° to 80°K electronic changes do not lead to volume changes greater than the experimental error, $\Delta V/V \sim 10^{-6}$.

* Supported by the U. S. Atomic Energy Commission and Office of Naval Research.

† Fulbright and Guggenheim Fellow on leave from the University of Sao Paulo, Brazil.

O5. Annealing of Volume Expansion and of the F Band in X-Ray Irradiated LiF.* D. A. WIEGAND AND S. MASCARENHAS,† *Carnegie Institute of Technology,* AND R. SMOLOCHOWSKI, *Princeton University.*—It has been shown previously[1] that the $\Delta V/V$ and F-center growth curves in LiF obtained at 80°K anneal out partially near 130°K. Upon re-irradiation at 80°K the F-center curve recovers quickly while the $\Delta V/V$ curve does not recover. In the present study a second annealing stage of $\Delta V/V$ and of the F band was found near room tem-

perature. In contrast to the 130°K stage upon re-irradiation at 80°K neither the growth curve of $\Delta V/V$ or of the F band recovers. The low-temperature annealing was found to be smaller than in the previous work, presumably because of different crystal purity. The irreversibility of the room-temperature annealing indicates the presence of defect recombination in contrast to the low-temperature stage.

* Research supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Fulbright and Guggenheim Fellow on leave from the University of Sao Paulo, Brazil.
[1] D. A. Wiegand and R. Smoluchowski, Phys. Rev. 116, 1069 (1959).

O6. Low-Temperature Bleaching of F Centers in KCl.* A. R. REINBERG AND L. I. GROSSWEINER, *Illinois Institute of Technology.*—Bleaching of F centers in x-rayed and additively colored KCl has been studied at 77°K.[1] Steady "F light" incident on the crystal establishes a photostationary equilibrium between F and F' centers. The application of additional light in the form of a 20-μsec pulse of high intensity displaces the system from equilibrium, to which it returns in a time varying with the steady light intensity. This displacement may be to higher F or F' center concentration depending on the spectral distribution of the light pulse. The quantum efficiency for the initial flash-induced change depends on the method of coloration and previous sample history. The lowest values are obtained for additively colored crystals and crystals which have been previously bleached with "F light" at room temperature. The return to equilibrium follows first-order kinetics, where the rate constant is independent of all factors except previous room temperature bleaching.

* Supported by the U. S. Atomic Energy Commission.
[1] A. R. Reinberg and L. I. Grossweiner, J. Chem. Phys. 30, 1616–1617 (1959).

O7. One-Dimensional Model of an X_2^- Center.* T. L. GILBERT, *Argonne National Laboratory.*—The manner in which the σ orbitals and energy levels of the X_2^- center evolve from the crystal orbitals and energy band when two neighboring ions are displaced toward each other has been studied using the model of a one-dimensional array of ions treated in the simplest LCAO approximation. It is found that any increase in the coupling between a neighboring pair of ions will cause two discrete levels to separate symmetrically from the band edges. A change in the diagonal matrix elements produces an asymmetry which, if large enough, can suppress one discrete level. Partial decoupling of the pair from the remainder of the chain will decrease, but not eliminate, the separation of existing discrete levels. The orbitals corresponding to discrete levels decrease exponentially in amplitude. When the discrete level to band edge distance is comparable with the bandwidth, the amplitude on neighboring ions is less than 1%; hence, for many calculations it is entirely justifiable to replace the σ orbitals of an X_2^- center by the molecular orbitals of an X_2^- ion.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

O8. Ferroelectricity in Mixed Bismuth Oxides with Layer-Type Structure.* E. C. SUBBARAO, *Westinghouse Research Laboratories* (introduced by G. Shirane).—Several compounds were synthesized with the formula $(Bi_2O_2)^{2+}(Me_{x-1}R_xO_{3x+1})^{2-}$ where Me can be mono-, di-, or trivalent ions, or a mixture thereof, R represents Ti^{4+}, Nb^{5+}, Ta^{5+}, etc., and $x=2$, 3, 4, etc. The crystal structure of these compounds, some of which were examined by Aurivillius,[1] comprises a stacking of perovskite-type units $(Me_{x-1}R_xO_{3x+1})^{2-}$ and of $(Bi_2O_2)^{2+}$ layers along the pseudo-tetragonal c axis. This structural arrangement leads to the same a ($\simeq$3.9 A) for all the compounds. The c parameter depends on the number of layers. Smolenskii *et al.*[2] found ferroelectricity in $PbBi_2Nb_2O_9$ of this structure-type (T_c 526°C). In the present work, ferroelectric behavior was discovered in other layer-type compounds: $PbBi_2Ta_2O_9$ (T_c 430°C), $PbBi_2Ti_2NbO_{12}$ (290°C), $BaBi_4Ti_4O_{15}$ (395°C), and $PbBi_4Ti_4O_{15}$ (570°C). Hysteresis loops were observed in $PbBi_2Ta_2O_9$ ceramics. Poled ceramics showed weak piezoelectric response, d_{33} of the order of 10^{-11} coul/N.

* Supported in part by contract with the U. S. Army-Ordnance Corps.
[1] B. Aurivillius, Arkiv Kemi 1, 463, 499 (1949); 2, 519 (1950).
[2] Smolenskii, Isupov, and Agranovskaya, Fiz. Tverdogo Tela 1, 169 (1959).

O9. Magnetic Behavior of Aged Au-Ni Alloys. F. B. KOCH AND J. M. SIVERTSEN, *University of Minnesota.*—A magnetic investigation of the aging process at low temperatures in the Au-Ni system has been made. It was found that, when alloys of 20–40 atomic percent nickel in gold are aged at temperatures between 100° and 200°C, a nickel-rich precipitate is formed. Supersaturated solid solutions were formed by homogenizing the alloys at high temperatures in the single phase region and then quenching rapidly to room temperature. The magnetization curve was then measured at various temperatures. After aging the sample for pre-determined time intervals, the magnetization curve of the specimen was remeasured after each aging period. The changes which occurred indicated that very small superparamagnetic particles were being formed during the aging process. As is typical for such aging behavior, the most rapid changes occur almost immediately, and the rate of the precipitation process decreased with time from this initial maximum. Evidence was found that the nickel-rich clusters do not continue growing but, instead, attain some stable size and then stop growing. The large amount of disregistry between the matrix and a pure nickel cluster suggests that strain energy may be the factor limiting growth of the segregate.

O10. Magnetic Susceptibility of Bis-Diazoaminobenzene Copper.* NORMAN ELLIOTT, *Brookhaven National Laboratory.*—Bis-diazoaminobenzene copper is a dimer in the crystalline state and contains two copper and six nitrogen atoms in an eight-membered ring. The magnetic moment of copper is lower than that generally observed for copper salts. The susceptibility behavior as a function of temperature will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Eckhart 133

(J. L. YNTEMA presiding)

Nuclear Structure II

P1. Decay of Ti^{45} and V^{47}.* M. K. RAMASWAMY, W. L. SKEEL, AND P. S. JASTRAM, *The Ohio State University.*—The decay of Ti^{45} and V^{47} has been studied using NaI counters and fast coincidence techniques. In the case of Ti^{45} a gamma ray of 270±10 kev was observed in coincidence with positrons. This establishes a level in Sc^{45} at 270 kev ($\frac{1}{2}^-$,$\frac{3}{2}^-$) to which 2.2% of

the decays ($\log ft = 5.4$) proceed. In the decay of V^{47}, an upper limit of 0.5% was set on the number of 160-kev photons per positron, giving a $\log ft$ lower limit of 7.2.

* Supported by the U. S. Atomic Energy Commission.

P2. Interaction of 7.5-Mev Protons with Copper and Vanadium.* BRUCE W. SHORE,† NATHAN S. WALL, AND JOHN W. IRVINE, JR., *Massachusetts Institute of Technology.*—The separate cross sections for interaction of 7.5-Mev protons have been measured for natural copper and vanadium. Angular distributions for elastic scattering are presented. The (inelastic scattering + alpha emission) cross sections are: copper = 266 mb and vanadium = 134 mb. The (p,n) reaction cross sections are: Cu^{65} = 537 mb, V^{51} = 555 mb. These data, along with a separate measurement of the polarization of 7.5-Mev protons from copper, are compared to optical model predictions indicating a somewhat low spin-orbit term in the potential and a further indication for a volume as distinguished from a surface absorption.

* This research was supported by the U. S. Atomic Energy Commission.
† Now at Analytic Services, Alexandria, Virginia.

P3. New Application of Delayed Coincidence Techniques for Measuring Lifetimes of Excited Nuclear States—Ca^{43} and Sc^{47}.* P. C. SIMMS, N. KOLLER, AND C. S. WU, *Columbia University.*—A new application of the delayed coincidence technique for measuring short nuclear lifetimes has been developed which is basically similar to the well-known prompt comparison method. The technique is applicable to nuclei which exhibit both "prompt" and "delayed" events that are not distinguishable in a pair of plastic detectors but are distinguishable by coincidences with a third detector. The measurements were performed with a transistorized time-to-pulse height converter and a 256-channel analyzer which was gated by a selective storage system. The prompt time-distribution and the delayed time-distribution were stored concurrently in separate halves of the analyzer. The centroids of the two distributions were then compared to obtain the lifetimes. The mean life of the second excited state of Ca^{42} ($4.8 \pm 0.3 \times 10^{-10}$ sec) and the first excited state of Sc^{47} ($< 5 \times 10^{-12}$ sec) were measured. Also, to check the equipment, the mean life of the first excited state of Hg^{198} ($3.5 \pm 0.5 \times 10^{-11}$ sec) was determined by the usual self-comparison method.

* This work partially supported by the U. S. Atomic Energy Commission.

P4. Systematic Errors in the Direct Measurement of Nuclear Lifetimes in the Sub-Millimicrosecond Region.* E. N. SHIPLEY,† F. J. LYNCH, AND R. E. HOLLAND, *Argonne National Laboratory.*—In measuring lifetimes of nuclear states by pulsed-beam techniques,[1] it is often desirable, as in other techniques, to measure lifetimes short compared to the resolving time of the apparatus. This has been accomplished by comparing the time spectrum of the nuclear gamma ray to that of a state known to have a very short lifetime. To obviate the energy dependence of such spectra when using a NaI(Tl) gamma-ray detector, a narrow pulse-height channel is selected which corresponds to the photopeak of the measured gamma ray and which consequently lies in the Compton distribution of the higher energy comparison gamma ray. Since the full energy of the comparison gamma ray is not dissipated in the detector, effects such as external scattering and Čerenkov radiation of photoelectrons escaping from the scintillator into the light pipe can distort the comparison spectrum. It is estimated that these effects cause an error of less than 0.05 mμsec. Attempts have been made to eliminate these effects by using a Compton spectrometer in which the scattered comparison gamma ray is detected in coincidence with the pulse in the primary detector.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Northwestern University.
[1] R. E. Holland, F. J. Lynch, and S. S. Hanna, Phys. Rev. 112, 903 (1958).

P5. Lifetimes of Excited States of Ni^{61}, Ga^{73}, Br^{79}, Rb^{85}, and Sb^{123}.* R. E. HOLLAND, F. J. LYNCH, AND E. N. SHIPLEY,† *Argonne National Laboratory.*—We have measured the lifetimes of the first excited states of the nuclei listed in the title by a pulsed-beam technique.[1] These states were Coulomb excited by a 3.25-Mev pulsed alpha-particle beam from the Argonne electrostatic accelerator; the de-excitation gamma rays were detected in a NaI(Tl) scintillator. Preliminary analysis of the data gives the results shown in Table I. The mean life of the state in Rb^{85} had previously been measured by Burgov *et al.*[2] as 1.14 ± 0.12 mμsec.

TABLE I.

Nucleus	Energy of state (kev)	Mean life (mμsec)
Ni^{61}	71	7.5 ± 0.5
Ga^{69}	322	<0.1
Br^{79}	219	<0.2
Rb^{85}	150	1.05 ± 0.15
Sb^{123}	161	0.82 ± 0.10

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Northwestern University.
[1] F. J. Lynch and R. E. Holland, Phys. Rev. 114, 825 (1959).
[2] N. A. Burgov, A. V. Davydov, and G. R. Kartashov, Soviet Phys.—JEPT 9, 1384 (1959).

P6. Analysis of Nuclear Excitation Functions near Threshold.* JAMES ROBB GROVER, *Brookhaven National Laboratory.*—A procedure has been devised for calculating cross sections for nuclear reactions within about 2 Mev of threshold, which includes the often very important effect of competition between gamma-ray and particle emission. The requisite formulas were developed using the spin-dependent statistical theory of nuclear reactions, so the treatment is most valid for medium to heavy nuclei at moderate bombarding energies. Input data required by the formulas are (1) the level density parameter a, (2) an effective nuclear moment of inertia δ_{eff}, (3) the ratio of radiation width to level spacing (Γ_γ/D) evaluated at some convenient energy, spin, and parity in the excited nucleus immediately preceding the product, (4) transmission coefficients $T_l(\epsilon)$ for the range of energies and type of particle in the final evaporation step, and (5) the energies, spins, and parities of the first few excited states in the product nucleus. By using a reasonable range of estimates for δ_{eff}, Γ_γ/D, and $T_l(\epsilon)$, experimental excitation functions near threshold for the reactions $Bi^{209}(p,2n)Po^{208}$ and $Sm^{144}(\alpha,3n)Gd^{145}$ were analyzed to find the corresponding range in values of a. The results are consistent with $a \sim 0.1A$ Mev^{-1} (A is the mass number) but inconsistent with $a \sim 2$ to 3 Mev^{-1}.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

P7. (p,n) Thresholds in Ti^{48}, Fe^{56}, and Sr^{88}.* J. W. NELSON, H. S. ADAMS, R. H. DAVIS, J. D. FOX, N. P. HEYDENBURG, H. S. PLENDL, R. K. SHELINE, AND G. M. TEMMER, *Florida State University.*—By using the slow-fast counter ratio tech-

TABLE I.

	Threshold energy (kev)				
	Ground state	1st excited	2nd excited	3rd excited	4th excited
$_{22}Ti^{48}$	4905 ± 10	5217 ± 10	5330 ± 10	5430 ± 10	5673 ± 10
$_{26}Fe^{56}$	5451 ± 10	5613 ± 10	5640 ± 14	5680 ± 14	5734 ± 14
$_{38}Sr^{88}$	4468 ± 14	4852 ± 10			

nique, we have determined the neutron thresholds in Table I with our Tandem Van de Graaff accelerator. The analyzing magnet was calibrated using the known $C^{13}(p,n)N^{13}$ (3237.2-kev) threshold. The new thresholds will be compared with Q values calculated from beta decay data as well as known excited states in the odd-odd residual nuclei.

* Supported in part by U. S. Air Force Office of Scientific Research.

P8. Orientation of As^{76}.* G. E. Bradley,† F. M. Pipkin, and R. E. Simpson,‡ *Harvard University.*—Dynamic nuclear orientation[1] has been used to study the $2^- \rightarrow 2^+$ 2.41-Mev β decay in As^{76}. The As^{76} was a donor atom in a silicon crystal, and it was oriented by saturation of the four forbidden transitions.[1] The angular distribution of the gamma rays following the 2.41-Mev β ray was measured with two scintillation counters. The nuclear and electron relaxation times were determined by observing the rate of growth and decay of the nuclear orientation. An analog computer was used to correct the initial orientation parameters for the effects of nuclear relaxation. The data indicate that all of the As^{76} atoms are not in the state represented by the simple donor model. From this experiment and experiments on the β-γ angular correlation and the β-γ circular polarization correlation, both the fraction of the atoms in the donor sites and the relative probability of the beta ray carrying off 0, 1, and 2 units of angular momentum have been determined.

* This research was supported by a grant from the National Science Foundation.
† Research performed while a National Science Foundation Faculty Fellow on leave from Western Michigan University.
‡ Now at University of Alaska.
[1] F. M. Pipkin and J. W. Culvahouse, Phys. Rev. **109**, 1423 (1958).

P9. Beta-Gamma Angular Correlation Measurements in Rb^{86}.* Helmut J. Fischbeck and Roger G. Wilkinson, *Indiana University.*—The angular correlation between the 0.72-Mev beta group and the 1.079-Mev gamma ray of Rb^{86} has been measured at nine beta-ray energies in the range 135 to 634 kev. A magnetic beta-ray spectrometer operated at 5% resolution and 5% transmission was used to define the beta-ray energy. The correlation coefficient ϵ was found to be positive and varied from 0.04 to 0.20 in the energy range covered. Comparison with theory shows that the "modified B_{ij} approximation" does not hold in this case and that small contributions from the matrix elements x and u (Kotani's notation) are present. It is concluded that no strong selection rule effect is operative to give a large reduction factor for the $\lambda=1$ matrix elements.

* Supported in part by the Office of Naval Research and U. S. Atomic Energy Commission.

P10. Decay of Pm^{146} and Eu^{146}. C. F. Schwerdtfeger, E. G. Funk, and J. W. Mihelich, *University of Notre Dame.**—The beta-decay of Pm^{146} (5.0- and 45.5-day) and the electron capture of Eu^{146} (58-day) lead to levels in Sm^{146}. These activities have been investigated with scintillation and magnetic spectrometers and coincidence and directional correlation techniques. Pm^{146} (5-day) decays with two beta branches of 1040 and 2460 kev which proceed to a 1422-kev level and the ground state, respectively. This level is depopulated by a 1423-kev γ transition and an 871.9–550.7 kev cascade. Eu^{146} and Pm^{146} (46-day) both populate levels of 551, 1181, 1599, 1906, and 2096 kev (γ rays of 99, 413.8, 550.7, 630.6, 726.8, and 916.5 kev). The long-lived Pm also feeds levels of 2196 and 2031 kev (γ rays of 190, 288.4, 432.2, and 1016 kev). The composite nature of the decay curves for the shorter lived components of the Pm^{146} decay indicates that the longer lived isomeric state lies above the shorter. Eu^{146} has a complex de-excitation spectrum (additional γ rays of 870, 1015, ~1230, 1335, ~1405, ~1515, 1610, and 1622 kev). Our results on the decay of Pm^{146} are in partial agreement with those of previous investigators. Proposed decay schemes will be presented.

* Work accomplished in part under U. S. Atomic Energy Commission contract.

P11. Decay of Tm^{172}.* R. G. Helmer and S. B. Burson, *Argonne National Laboratory.*—The radioactive nuclide $_{69}Tm^{172}$ was obtained through the decay of Er^{172}. The erbium activity was produced by successive neutron capture in erbium oxide enriched in Er^{170}. The irradiations were made in the Materials Testing Reactor at Arco, Idaho. In addition to three thulium activities, these samples contained six active contaminants. Pure thulium sources were obtained by use of an ion-exchange column. Scintillation studies were conducted with a 256-channel coincidence scintillation spectrometer. These measurements indicate the presence of at least 17 gamma-ray transitions. The beta-ray spectrum was studied with a 180° magnetic beta-ray spectrometer as well as with scintillation coincidence techniques. These measurements indicate the presence of five components: 1.83, 1.65, ~0.74, ~0.46, and ~0.33 Mev. A level scheme for Yb^{172} will be presented which has excited states at 0.079, 0.260, 1.17, 1.45, ~1.53, ~1.59, ~1.63, and ~1.71 Mev. The experimental data are consistent with the previously proposed interpretation of the first two excited states as members of a $K=0$ rotational band based on the ground state. Possible interpretations of the other levels in terms of the collective model will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P12. Low Lying States of Yb^{173}.* R. C. Pilger, Jr., J. W. Bichard, and J. W. Mihelich, *University of Notre Dame.*—Nilsson's wave functions have been employed to calculate the rotational-particle coupling among the low-lying nuclear states of Yb^{173}, yielding satisfactory agreement with the observed energy spectrum.[1] The resultant wave functions have been used to calculate the relative intensities and dipole-quadrupole mixings of the relevant nuclear transitions, yielding satisfactory agreement with the observed values. The predicted relative phases of the dipole and quadrupole matrix elements have been confirmed by γ-γ directional correlations carried out with a source of electron-capturing Lu^{173}.

* Work supported in part under U. S. Atomic Energy Commission contract.
[1] J. W. Bichard, J. W. Mihelich, and B. Harmatz, Phys. Rev. **116**, 720 (1956).

P13. Binding Energy Formula. W. Hornyak and R. U. Ayers,* *University of Maryland.*—A rather simple "model" nuclear interaction is used in order to obtain a mathematically tractable expression for the nuclear mass spectrum. The basic approximation is to use central potentials whose corresponding diagonalized K matrix in configuration space is an attractive or repulsive square-well. The variable parameters are the four square-well depths, the width being chosen to agree with two-body scattering data. In addition, the density distribution in a nucleus is chosen to have a trapezoidal form, as suggested by Hofstader's experiments, but the "edge thickness," or fall-off distance, is allowed to be a function of mass number. The procedure is to fix all the parameters by forcing the binding energy and most stable Z value to fit experiment for one nucleus (Pb 208) and then force the binding energy alone to fit all other nuclei by varying the edge thickness appropriately. The results are then tested by comparing most stable Z values and the variation of edge thickness against experiment. Numerical results are given.

* Now at The G. C. Dewey Corporation.

SATURDAY MORNING AT 9:30

Social Sciences 122

(W. F. FRY presiding)

High-Energy Physics

Q1. Structure of Nucleons. JENO M. BARNOTHY, *Evanston, Illinois.*—A model is suggested, based on the assumption that elementary particles are closed universes with smaller length and mass units, embedded in a four-dimensional continuum. Depending upon whether they intersect our space from the "right" or "left," they become observable as particles or anti-particles. The inability to distinguish between an absolute "right" and "left" leads to baryon and lepton conservation laws. Strong interactions are symmetrical with respect to the fourth dimension and manifest parity conservation in the usual three-dimensional description. Weak interactions are asymmetrical in the fourth dimension and will obey parity conservation only if the fourth coordinate, i.e., particle to anti-particle change, also is considered. Nuclear forces are gravitational forces between rest masses, determined by the metric of the smaller world. The theory predicts for the proton in addition to its positive Coulomb charge a negative unit charge with Yukawa potential, simulating a deviation from the Coulomb potential. The deviations from point scattering laws are at present scattering energies, not a consequence of the finite size of nucleons. Computed form factors will be compared with experimental results of Hofstadter, Wilson, and Hand, and the feasibility of an experimentum crucis discussed.

Q2. High-Energy Potential Scattering. S. ROSENDORFF, *Washington University,* AND S. TANI, *Washington University and New York University.*—The phase shifts in potential scattering of a relativistic particle tend at high energies to the first term in their expansion into powers of the potential. This result, first shown by Parzen follows from the property of the matrix element of the potential in momentum space. In each partial wave $(K'|V|K)$ is peaked sharply at $k=k'$ and almost symmetrical around there. The amplitude which comes from the second-order phase shift, when summed over different angular momenta, is small compared to the one which comes from the square of the first-order phase shift. These remarks support the Schiff-Moliére approximation for high-energy potential scattering.

Q3. Quantum Mechanics of the μ-Mesonic Molecule: *p*-μ-*p*. P. E. PHILLIPSON, *University of Chicago.*—In cases such as the *p*-μ-*p* system, the muon to proton mass ratio is such as to question the applicability of the Born-Oppenheimer separation which is valid for the analogous H_2^+(*p*-*e*-*p*) molecule. A scheme is presented where the total molecular wave function for three particles of arbitrary masses is constructed in such a way that the Born-Oppenheimer approximation is not invoked. The *p*-μ-*p* wave function has the form

$$\Psi_{k,m_k}=\sum_{jl} a_{jl}\psi^{jl}_{k,m_k};$$

$$\psi^{jl}_{k,m_k}=\sum_{m_j} C(jlk;\, m_j m_k-m_j)\chi_{j,m_j}(p\text{-}p)\phi_{l,m_l}(\mu).$$

$C(jlk;\, m_j m_k-m_j)$ is a Clebsch-Gordan coefficient coupling the $(p\text{-}p)$ and (μ) wave functions to produce a three-particle wave function of total angular momentum k. In this coupled scheme χ_{j,m_j} is interpreted as a "nuclear molecular orbital," and ϕ_{l,m_l} as a one-center molecular orbital. S, P, $D\cdots(k=0, 1, 2\cdots)$ states can be generated readily, and all integrals are of the simple one-center type. The implications of a nuclear molecular orbital, relationships between the Born-Oppenheimer separation and the Uncertainty Principle, and numerical results are discussed.

Q4. Interaction Radius in Direct Reactions.* LEONARD S. RODBERG, *Los Alamos Scientific Laboratory and University of Maryland.*—In the direct interaction theory of nuclear reactions a parameter appears which describes the radius of the surface region in which the direct interaction takes place. Fits to experimental data using Born approximation theories lead to interaction radii which are considerably larger than nuclear radii determined by other means. This is a simple consequence of the distortion of the incident and outgoing waves, described in terms of an optical potential. This potential increases the relative momentum in the region of interaction, leading to smaller interaction radii for a given angular-momentum transfer. The energy independence of observed direct reaction angular distributions also can be understood in terms of the modified momentum inside the nuclear potential.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Q5. Interaction of 142-Mev Negative Pions with Deuterium.* E. G. PEWITT, G. B. YODH, M. DERRICK, J. FETKOVICH, AND T. FIELDS, *Carnegie Institute of Technology.*—The interaction of 142±7-Mev negative pions with deuterium has been studied using a 15-cm deuterium bubble chamber in a 12.7-kgauss field. The elastic and inelastic events were separated by an angle correlation, coplanarity of the event, and the range of the positive particle. The preliminary results based on a track length of 25 km are given in Table I. The total cross section for the three reactions $\pi^-+d\rightarrow n+n$, $n+n+\pi^0$ and $n+n+\gamma$ was 34.4±2.6 mb. A comparison of the elastic scattering data with theoretical predictions will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

TABLE I (for Abstract Q5).

Reaction	Total cross section (mb) 30°–180°	Differential lab cross section (mb/st) (pion lab angle in deg) 30°–40°	40°–50°	50°–60°	60°–90°	90°–120°	120°–150°	150°–180°
Elastic ($\pi^-+d\rightarrow\pi^-+d$)	22.2±1.3	9.47±0.95	5.01±0.60	2.43±0.29	1.59±0.16	0.96±0.10	0.63±0.09	0.85±0.14
Elastic plus inelastic ($\pi^-+d\rightarrow\pi^-+d$) and ($\pi^-+d\rightarrow\pi^-+n+p$)	117.0±7.0	23.4±4.0	10.1±2.7	8.4±2.5	6.05±0.67	11.0±0.92	10.8±1.13	11.0±1.86

Q6. Anomalous Emission of Neutral Pions.* D. T. KING, *The University of Tennessee.*—In 600-micron Ilford K5 emulsions which had been exposed to a beam of 10^4 cm^{-2} 3.5 Bev/c negative pions, the tracks of 700 electron pairs have been examined. Those pairs (about 5%) evidently due to secondary cascade effects are excluded. Tracing the photon paths backward for distances exceeding 100 μ indicates that only one pair is due to Dalitz or close Bethe-Heitler conversion in relation to a nuclear interaction. In a similar experiment[1] with about 550 electron pairs found in an exposure of 400-μ G5 emulsions to 2.7-Bev protons, nine such closely associated pairs were observed, a reasonable expectation from the theory.[2] The spectral distribution of quantum energy in each experiment is consistent with the emission of neutral pions of rather low energies. It is considered unlikely that the small number of close pairs in the fast pion exposure is due to a statistical fluctuation, and efforts to detect systematic errors continue.

* Supported by the National Science Foundation.
[1] D. T. King, Bull. Am. Phys. Soc. Ser.II, **2**, 286 (1957).
[2] R. H. Dalitz, Proc. Phys. Soc. (London) **ALXIV**, 667 (1951).

Q7. Large-Angle Negative Pion-Proton Elastic Scattering at 1.5 Bev/c Measured by Homogenous Luminescent Chamber.* K. W. LAI, L. W. JONES, AND M. L. PERL, *University of Michigan.*—As a part of pion-proton scattering experiments with the Homogeneous Luminescent Chamber,[1] we are studying π^--P elastic scattering between values of $\cos\theta$ of $+0.7$ and -0.9 where θ is the scattering angle of the pion in the barycentric system. A CH_2 target was placed in between two NaI crystals, and two coplanar scintillation counters outside of the NaI crystals selected events occurring within $\pm 10°$ of the vertical plane. To subtract out pseudo-elastic scattering from carbon, a graphite target was used. The image intensifier system was triggered by the counters to record the scattered particles. The pictures were scanned using kinematics and ionization as criteria for elastic scattering. The cross section showed a minimum at $\cos\theta = 0.2$ and rose to a plateau at backward angles. We have repeated this experiment using a liquid hydrogen target at incident pion momenta of 1.5 Bev/c, 2.0 Bev/c, and 2.5 Bev/c, and analysis of this is in progress.

* Supported by the Office of Naval Research.
[1] L. W. Jones and M. L. Perl, International Conference on High-Energy Accelerators and Instrumentation-CERN, 1959.

Q8. Single Scattering of 2 Bev/c Muons in Nuclear Emulsions.* C. Y. KIM, S. KANEKO,† AND Y. B. KIM, *University of Washington.*—Masek *et al.*[1] have measured nuclear scattering of high-energy muons (1.95 ± 0.04 Bev/c) produced at the UCLRL Bevatron from pion decays in flight. Over momentum transfer of 100 to 300 Mev/c, the counting experiment[2] is in good agreement with the appropriate electromagnetic theory prediction and does not support the "anomalous" scattering reported by some cosmic-ray experiments. To investigate this problem by an independent technique, nuclear emulsion stacks exposed to the same muon beam scanned for single scattering from emulsion nuclei. So far we have followed 750 m of muon tracks and observed 680 single scatterings in the angular region of 0.5 to 3 deg, corresponding to the momentum transfer of 17 to 100 Mev/c. In the muon tracks accepted for scanning, the pion impurity is less than 0.5%, and no correction is required on this account for the momentum transfer region mentioned above. The observed scattering distribution is in agreement with the electromagnetic theory prediction based on the form factors given by Cooper and Rainwater.

* Supported by the Office of Naval Research.
† On leave from Osaka City University.
[1] G. E. Masek, D. L. Heggie, Y. B. Kim, and R. W. Williams, Bull. Am. Phys. Soc. Ser. II, **5**, 369 (1960).
[2] Reported by G. E. Masek at the 1960 Rochester High-Energy Physics Conference.

Q9. Cosmon Explanation of MIT 4.10^{19} ev Cosmic Rays. JOSEPH G. BARREDO, *C.S.I.C.*—De Broglie, Bohm, and Barredo[1] predicted the existence of metacoordinates (hidden coordinates). Barredo predicted them by triondynamics. Triondynamics predicted also that (1) cosmic rays are produced by cosmons, i.e., trions formed by a dipole in front of a carrier spinning around the configuration center; (2) cosmons of cross section $<10^{-42}$ cm^2 were to be found; (3) the small cross section of cosmons of energies $>10^{18}$ ev will make them very difficult to detect; (4) field theory will be unable to explain or even classify high-energy phenomena; (5) Fermi's theory of cosmic rays was misleading. These predictions are confirmed now by Rossi's MIT group finding of 4.10^{19} ev cosmic rays (to be published), which, in agreement with triondynamics, is produced by a cosmon of cross section 10^{-56} cm^2 coming from the outside of the galaxy. Triondynamics predicts also that (1) similar cosmons could be found in the nucleus, if sufficiently powerful superaccelerators were available; (2) these "particles" need not be designated with special names because all of them are trions whose properties are a function of its metacoordinates.

[1] H. Margenau and R. A. Mould, Phil. Trans. Roy. Soc. (London) **24**, 297 (1957); H. Dingle, Nature **183**, 1761 (1959) and Phil. Trans. Roy. Soc. (London) **27**, 233 (1960); J. G. Barredo, Naturwissenschaften**1 5**, 346 (1956) and Bull. Am. Phys. Soc. Ser. II, **5**, 365 (1960).

SATURDAY AFTERNOON AT 1:30

Kent 106

(H. ANDERSON presiding)

Invited Papers in Meson Physics

R1. Nuclear Structure Effects in μ-Mesic Atoms. E. P. HINCKS, *University of Chicago.* (30 min.)

R2. A Search for Neutrinoless Conversion of Muon into Electron. R. SARD, *Washington University.* (30 min.)

R3. Internal Pairs Formed in π-Meson Reactions. S. C. WRIGHT, *University of Chicago.* (30 min.)

R4. π-Meson Capture in Hydrogen and H-D, H-He Mixtures. G. B. YODH, *Carnegie Institute of Technology.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Mandel Hall

(S. S. HANNA presiding)

Mössbauer Effect

S1. Further Data on the Weight of Photons. R. V. POUND AND G. A. REBKA, JR., *Harvard University.*—Since a report of initial results,[1] our measurement of the influence of gravity over a 70-ft height on the frequency of the recoil-free 14-kev γ ray of 0.1-μsec Fe^{57} has been carried to higher precision. The apparatus has been operated nearly continuously, and data have been accumulated sufficient to reduce statistical uncertainties below an rms value of 4% of the anticipated frequency shift. Among modifications made to reduce possible systematic errors is continuous automatic cycling of the slow steady motion of the source. During alternate 5-min intervals the motion is upward and downward. A separate set of scalers records the counts for each sense of the motion. A system of permanent magnets has been added to provide parallel polarizing fields in the planes of the source and the absorbers. Some runs have been made using carefully annealed natural iron absorbers instead of the isotopically enriched films plated on beryllium used for most runs. The gravitational effect found agrees with gh/c^2 in each partial run, as well as in the over-all average, within the appropriate statistical uncertainties.

[1] R. V. Pound and G. A. Rebka, Jr., Phys. Rev. Letters **4**, 337 (1960

S2. Measurement of Frequency Shift in Accelerated Systems, Using the Mössbauer Effect. H. E. BÖMMEL AND K. DRANSFELD, *Bell Telephone Laboratories, Inc.*—We have used the following system: Two identical piezoelectric quartz transducers were simultaneously exited to longitudinal vibrations at a frequency of a few Mc/sec. To one surface of each transducer was attached a piece of 1-mil thick stainless steel foil, one of them carrying the Fe^{57} source, the other one serving as absorber. Care was taken to drive both transducers at the same phase and amplitude to avoid direct Doppler shift of the γ line. Source and absorber then can be regarded as being in one and the same accelerated system. If the transducers vibrate with amplitude a and angular frequency ω, and are separated by a distance d, one expects then to find a relative γ-resonance shift $\Delta\nu/\nu = a\cdot\omega^2\cdot d/C^2$ between source and absorber. Based on the principle of equivalence, this also can be interpreted as caused by a difference in "gravitational potential." We have observed such a shift, proportional to d. We also have performed experiments in a small ultracentrifuge with results similar to Hay *et al.*[1]

[1] H. J. Hay, J. P. Schiffer, T. E. Cranshau, and P. A. Egelstaff, Phys. Rev. Letters **4**, 165 (1960).

S3. Possible Parity and Time Reversal Experiments Using the Mössbauer Effect.* MASATO MORITA, *Columbia University.*—Consider a beta-gamma cascade of $j \rightarrow j_1$, $m_1 \rightarrow j_2$, m_2, where hfs is the nuclear Zeeman effect. The gamma ray, which is to be resonant scattered or absorbed, is fixed in direction. The beta ray is observed in coincidence with one of the Mössbauer satellites for which m_1 and m_2 are well defined. In this case, the beta-ray angular distribution has an asymmetry with respect to the direction of the magnetic field, since the j_1 state is polarized. The asymmetry in this case is of the order of unity (times the probability of the recoiless transition). This experiment does not require the use of an analyzer for the circular polarization of the gamma ray or the low-temperature technique, assuming the Mössbauer effect is observable at room temperature. The resulting improvement in accuracy will make possible the measurement of the v/c dependence of the asymmetry due to the parity nonconservation of beta interaction. When the absorption line consists of more than two Mössbauer satellites with different m_1–m_2, an experiment can be designed for testing time reversal invariance in beta interaction.

* This work partially supported by the U. S. Atomic Energy Commission.

S4. Temperature Dependence of the Mössbauer Spectrum in Fe^{57}.* D. H. VINCENT,† R. S. PRESTON, J. HEBERLE, AND S. S. HANNA, *Argonne National Laboratory.*—The hyperfine spectrum in the resonant absorption of 14-kev radiation from Fe^{57} in metallic iron samples has been studied as a function of temperature from 77° to 1220°K. Two effects have been observed. The first is the shift of the absorption lines to lower energy as the temperature of the absorber is raised. This effect has been discussed by Pound and Rebka[1] and by Josephson.[2] The second effect is a contraction of the absorption spectrum as the temperature is increased. This effect is attributed to a decrease in the internal magnetic field at the nucleus. The connection between the change in the field at the nucleus and the change in saturation magnetization will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Michigan.
[1] R. V. Pound and G. A. Rebka, Jr., Phys. Rev. Letters **4**, 274 (1960).
[2] B. D. Josephson, Phys. Rev. Letters **4**, 341 (1960).

S5. Frequency Distribution of Resonance Line vs Delay Time.* C. S. WU, Y. K. LEE, N. KOLLER, AND P. C. SIMMS, *Columbia University.*—The frequency distribution of resonance line of Fe^{57} at different time intervals T after the formation of the 14.4-kev excited state has been investigated with the aid of the Mössbauer effect. The detection of the preceding radiation (123-kev line) served as the signal of the formation of the 14.4-kev excited state. The unsplit Fe^{57} line from a stainless steel source (#302, 8.3 mg/cm^2) with a similar stainless steel absorber was used for the study. A continuous Doppler motion and velocity indication was provided by a system of two transducers together with a 256-channel analyzer. In varying the delay time from one to one quarter mean lifetime, the observed full line width broadens from 0.4 mm/sec to 10 mm/sec. Furthermore, the theoretically predicted ringing effects beyond the central resonance line were clearly shown and in good agreement with theory.[1]

* This work partially supported by the U. S. Atomic Energy Commission.
[1] M. Hamermesh, Argonne National Laboratory Summary Rept., ANL-6111, February, 1960; R. E. Holland *et al.*, Phys. Rev. (to be published).

S6. Hyperfine Structure of Fe^{57} in Yttrium-Iron Garnet from the Mössbauer Effect. C. ALFF, AND G. K. WERTHEIM, *Bell Telephone Laboratories, Inc.*—The hyperfine structure of Fe^{57} in yttrium-iron garnet ($Y_3Fe_2(FeO_4)_3$) has been obtained through the Mössbauer effect. The source used was Co^{57} diffused into stainless steel. The absorber was a 0.002-in. thick slice of a single crystal of yttrium-iron garnet, cut normal to a [110] direction. The iron in this material is located in two nonequivalent sites, tetrahedral and octahedral. Because of the symmetry of the crystal, the electric field gradient tensor is axially symmetric at both sites, the axes being [111] at the octahedral site and [100] at the tetrahedral site. Data were taken with the internal magnetic field aligned in both [111] and [100] directions by application of an external magnetic field. The axes of symmetry of all octahedral sites make an angle of 55° with the magnetic field when the field is in a [100]

direction, and the axes of symmetry of all tetrahedral sites make an angle of 55° with the magnetic field when the field is in a [111] direction. For each direction of magnetization, the absorption lines of Fe^{57} at both sites have been resolved. The magnetic field at an Fe^{57} nucleus has been found to be 3.9×10^5 oe at a tetrahedral site and 4.7×10^5 oe at an octahedral site when the crystal is at room temperature. The magnitude of quadrupolar interaction has been determined for both sites.

S7. Measurement of the Mössbauer Effect in Ni^{61}. FELIX E. OBENSHAIN AND HORST WEGENER, *Oak Ridge National Laboratory.*—The Mössbauer effect is observed in Ni^{61} using a Ni^{64} source and a natural nickel absorber foil. The Ni^{61*} was obtained by $Ni^{61}(p,\alpha)Co^{61}\xrightarrow{\beta^-(99\text{ min})}Ni^{61*}$ giving a nickel Mössbauer nucleus in a nickel host lattice. The magnitude of the effect at $T=80°K$ is about 4% for a 400-mg/cm² absorber foil (natural nickel). The temperature dependence yields a Debye temperature between 413° and 437°K (Debye model). The velocity dependence shows no Lorentz shape. The measured half-width is 1.65 mm/sec. A recent electronic determination[1] of the lifetime of this 71-kev state indicates a natural half-width of 0.37 mm/sec. The increased half-width observed in our experiment may be understood in terms of a magnetic hyperfine splitting. The moment of the ground state is known. The internal field H and the magnetic moment μ_e of the first excited state are unknown. This measurement gives a connection between the two quantities $\mu_e(H)$. The first excited state of Ni^{61} is probably a single particle state so that μ_e may be estimated with reasonable confidence. By using the calculated value of μ_e, we obtain $H\approx57$ kgauss.

[1] A. Schwarzchild (private communication).

S8. Remarks on Lipkin's Sum Rule for the Mössbauer Effect.* HARRY LUSTIG, *The City College of New York.*—Lipkin's sum rule[1] gives the average energy transferred to a crystal lattice upon emission of a nuclear gamma ray. While this rule shows how recoiless emission *may* occur, it does not say whether the Mössbauer effect actually *will* occur in a given system; to obtain a clear-cut answer to the latter question the probability for zero energy transfer (the Debye-Waller factor) actually must be calculated. We propose a method whereby a good indication of the suitability of a system for Mössbauer experiments may be obtained without a detailed calculation. The method is to compare the variance in the energy transfer to the ground-state energy of the system. The expression for the variance depends on the difference between the expectation value of the square of the momentum of the emitting nucleus and the square of the expectation value of the momentum of this nucleus. These quantities are often known, or they may be estimated, even for complicated systems, without detailed knowledge of the wave functions. Our criterion of comparison is shown to be correct for crystals and may be applied to more complicated systems, such as liquids.

* Supported by the National Science Foundation.
[1] H. J. Lipkin, Ann. Phys. **9**, 332 (1960).

S9. Mössbauer Effect in Ferromagnetic Alloys of Sn^{119}.* S. S. HANNA, L. MEYER-SCHÜTZMEISTER, R. S. PRESTON, AND D. H. VINCENT,† *Argonne National Laboratory.*—Hyperfine splittings of the two lowest levels in Sn^{119} were observed by studying the resonant absorption of the 24-kev γ radiation of Sn^{119m} in two ferromagnetic alloys, Mn_4Sn and Mn_2Sn. Most of the measurements were made at liquid nitrogen temperature. In the case of Mn_2Sn, the hyperfine splitting was especially large. This splitting disappeared when the temperature of the Mn_2Sn absorber was raised to room temperature, which is well above the Curie point (~0°C). The observed hyperfine structure will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Michigan.

S10. Curie Point and Mössbauer Effect. STANLEY RUBY AND PAUL A. FLINN, *Westinghouse Electric Corporation.*—A direct demonstration of the importance of long-range magnetic order[1] on the hyperfine splitting as observed by the Mössbauer effect has been made. A special iron containing metallic foil (18% Cr, 40% Ni, 42% Fe atomic weight) was prepared to bring the Curie point to a convenient temperature, −38°C. The absorption pattern at 30°C clearly shows the absence of hyperfine splitting. The pattern at −195°C extends to about 5 mm/sec, corresponding to about 300 kgauss, albeit with no resolvable peaks. This is probably the result of the statistical fluctuations in nearest neighbor composition for the various iron atoms.

[1] G. K. Wertheim, Phys. Rev. Letters **4**, 403 (1960).

S11. Mössbauer Effect in Some Iron Compounds.* R. L. INGALLS, GEORGE LAND, AND S. DE BENEDETTI, *Carnegie Institute of Technology.*—The nuclear resonant scattering of gamma rays by Fe^{57} in a variety of compounds containing ferrous and ferric iron ions has been studied by use of the Mössbauer effect. The source of Co^{57} was diffused in stainless steel, providing an unsplit 14.4-kev emission line. The transmission vs velocity curve in the specimens (observed at liquid nitrogen temperature to augment the effect) depends mainly upon the valence state, varying only slightly with the negative ion. In Fe^{++} two absorption peaks are observed. Their positions in cm/sec are: $FeCl_2\cdot4H_2O$, (−0.02, +0.30); $FeSO_4\cdot7H_2O$, (−0.02, +0.33); and $Fe(NH_4)_2(SO_4)_2\cdot6H_2O$, (+0.01, +0.29). A positive velocity corresponds to the source approaching the absorber. The splitting, which for each ferrous compound is ~0.3 cm/sec, is interpreted as resulting from the quadrupole moment of the excited nucleus. Calculations of the magnitude of the nuclear quadrupole moment, based on the measured splitting and available tabulated electronic wave functions, are in progress. Preliminary results are of reasonable order of magnitude (0.2 barn). In Fe^{+++} compounds a broad absorption curve near zero velocity is observed. Some hints of fine structure in this line have been noticed, and more detailed measurements are in progress.

* Supported by the Office of Naval Research.

SATURDAY AFTERNOON AT 1:30

Breasted Hall, The Oriental Institute

(F. C. BROWN presiding)

Knight Shift Studies and Metals

Invited Paper

T1. Correlation between Superconductivity and Nuclear Magnetic Resonance. V. JACCARINO, *Bell Telephone Laboratories, Inc.* (30 min.)

Contributed Papers

T2. Correlations between Superconductivity and Susceptibility. H. J. WILLIAMS AND R. C. SHERWOOD, *Bell Telephone Laboratories, Inc.*—Recently[1] correlations have been found between the nuclear magnetic resonance properties and the superconducting transition temperature T_s of intermetallic compounds having the β-W structure. Measurements of the temperature dependence of the bulk susceptibility of these metals now have been made. We find the temperature dependence of the susceptibility to be largest for the high-temperature superconductors and the nonsuperconductors to be temperature independent. All measurements were made above T_s. An interpretation of these and the NMR results is given in the following paper.[2]

[1] W. E. Blumberg, J. Eisinger, V. Jaccarino, and B. T. Matthias, Phys. Rev. Letters **5**, 149 (1960).
[2] A. M. Clogston and V. Jaccarino, Bull. Am. Phys. Soc. Ser.II, **5**, 430 (1960).

T3. Susceptibilities and Negative Knight Shifts in Certain Intermetallic Compounds. A. M. CLOGSTON AND V. JACCARINO, *Bell Telephone Laboratories, Inc.*—Knight shift measurements recently have been made on a series of compounds of the β-Wolfram structure V_3X, namely, V_3Si, V_3Ga, V_3Ge, V_3As, V_3Sb, and V_3Sn.[1] More recently susceptibilities have been measured on some of these compounds.[2] It is observed that (a) materials with a high superconducting transition temperature show temperature-dependent Knight shifts and susceptibilities, (b) the vanadium shifts K_v are positive and decrease with decreasing temperature, and (c) the X site shifts K_x are negative and increase in magnitude with decreasing temperature. A simple model will be offered which uses the Heine[3] exchange polarization mechanism to relate the sign and temperature dependence of K_v and K_x to the temperature-dependent susceptibility.

[1] W. E. Blumberg, J. Eisinger, V. Jaccarino, and B. T. Matthias, Phys. Rev. Letters **5**, 149 (1960).
[2] H. J. Williams and R. C. Sherwood, Bull. Am. Phys. Soc. Ser. II, **5**, 430 (1960).
[3] V. Heine, Phys. Rev. **107**, 1002 (1957).

T4. Band Structure of Gray Tin from Knight Shift Measurements. W. E. BLUMBERG AND J. EISINGER, *Bell Telephone Laboratories, Inc.*—By measuring the nuclear magnetic resonance of Sn^{119} in intrinsic gray tin between 200°K and 300°K, a temperature-dependent Knight shift k was obtained. k was found to increase 4×10^{-5} in the above temperature range, and this change can be attributed to a larger conduction electron concentration at the higher temperature. The sign of k indicates that the electron g factor g_e is positive and that the band structure of gray tin is therefore unlike that of InSb.[1] If one instead assumes a band structure similar to that of Si or Ge, so that $g_e \approx 2$, the single valley reduced effective mass of the lighter charge carrier m_l^* can be obtained by comparing k with the temperature-dependent bulk susceptibility of gray tin.[2] In this way one finds $m_l^* = 0.3 \pm 0.05$.

[1] L. M. Roth, B. Lax, and S. Zwerdling, Phys. Rev. **114**, 90 (1959).
[2] G. Bush and E. Mooser, Helv. Phys. Acta **26**, 611 (1953).

T5. Effect of Isotopic Composition on Temperature Dependence of the Resistance of Lithium.* R. G. LEFFLER AND D. J. MONTGOMERY, *Michigan State University.*—Studies on the dependence of resistance of separated lithium isotopes on temperature and isotopic mass have shown[1,2] a qualitative agreement with the predictions of the Bloch-Grüneisen theory. The present work was undertaken to improve the precision of measurement, to extend the temperature range for isotopically pure samples, and to examine the effect of isotopic composition in isotopically impure samples. The isotopically pure samples were compared with the theory in the form $(\rho^6/\rho^6_{20^\circ})/(\rho^7/\rho^7_{20^\circ})$ and good agreement was found for a choice of θ_R of about 325°K for the region above 70°K. Below this temperature there was marked disagreement. The isotopically impure mixtures behaved qualitatively, as would be expected for a single species of the average isotopic mass.

* Supported by U. S. Army Office of Ordnance Research and U. S. Atomic Energy Commission.
[1] D. D. Snyder, R. G. Leffler, and D. J. Montgomery, Bull. Am. Phys. Soc. Ser. II **2**, 299 (1957); D. D. Snyder and D. J. Montgomery, Phys. Rev. **109**, 222 (1958).
[2] V. P. Dugdale and D. Gugan (private communication).

T6. Residual Resistivity of Gallium at 4.2°K and Related Measurements.* L. R. WEISBERG AND R. M. JOSEPHS, *RCA Laboratories.*—Measurements of the ratio of resistivity at 4.2°K to that at room temperature have been utilized to determine the impurity content of very high purity gallium. Single crystal wires of gallium are conveniently grown in Teflon tubing. To separate the effects of impurity, lattice, and surface scattering, resistivity ratio measurements were made both as a function of impurity content and wire diameter, and also the resistivity was measured in the range of 1.27°K to 43°K. No low-temperature rise in resistivity was observed. It is found that the value of the resistivity ratio resulting from lattice scattering is 0.6×10^{-5}, that resulting from surface scattering in a wire with a 1-mm diam is 1.5×10^{-5}, while scattering from grain boundaries and from dislocations is negligible. The electron mean free path is found to be 1.2 mm at 4.2°K at a resistivity of about 4×10^{-22} esu, implying that the effective number of free electrons per atom is 0.3. The increase in the resistivity ratio resulting from 1 atomic ppm of In, Tl, As, Ge, Sn, Pb, Zn, Cu, and Ag was found to be, respectively, $10^{-5}\times0.07$, 40, 1.0, 1.1, 0.15, 1.3, 0.9, 1.8, and 0.18.

* Sponsored by the Electronics Research Directorate of the Air Force Research Division—Air Research and Development Command.

T7. Intermediate State of Superconducting Films. WARREN DE SORBO AND V. L. NEWHOUSE, *General Electric Research Laboratory.*—The intermediate state structures of superconducting films of tin and lead have been rendered visible with the magneto-optic effect in cerous phosphate glass.[1,2] The fields are applied normal to the surfaces. The structures differ appreciably from those observed in the respective bulk metals, in general, resembling the patterns seen in "hard" superconductors.[3,4] However, depending on the substrate and strains and thickness of the film, more complex "fibrous" structures also are clearly visible. In all patterns observed, wall motions occur abruptly as in "hard" superconductors.[1-4] Flux density of trapped-in flux after the field has been decreased to zero from H_c is approximately 100 oe for tin film compared to 40 oe for the bulk material; also, 150 oe for lead film as compared to 100 oe for unstrained single crystal lead. Some preliminary results also will be presented on the influence of dc current on frozen-in flux patterns.

[1] P. B. Alers, Phys. Rev. **105**, 104 (1957); Phys. Rev. **116**, 1483 (1959).
[2] W. De Sorbo, Phys. Rev. Letters **4**, 406 (1960).
[3] A. L. Schawlow, Phys. Rev. **101**, 573 (1956).
[4] A. L. Schawlow, G. E. Devlin, and J. K. Hulm, Phys. Rev. **116**, 626 (1959).

T8. Influence of Pressure on the Superconducting Critical Field of Aluminium. J. L. OLSEN,* *Eidgenössische Technische Hochschule Zürich.*—The change in critical field H_c with pressure p in aluminium has been measured between 0.3°K and the transition temperature T_c. We find

$$\partial H_c/\partial p = -[3.1\pm0.2+(1.7\pm0.2)(T/T_c)^2]\times10^{-9}$$

gauss dyne^{-1} cm^2.

From these results the dependence of the normal state electronic specific heat γT upon volume v may be calculated. This

is given by $d \ln\gamma/d \ln v = 8 \pm 4$. Recent work in Zürich in this field is discussed.

* At present on leave of absence at Department of Physics and Astronomy, Ohio State University.

T9. Electric Properties and Energy Bands of U-Mo Alloys. F. J. BLATT, *Clarendon Laboratory, Oxford.**—The data of Chandrasekhar and Hulm (resistivity), of Berlincourt (Hall effect), and of Goodman *et al.* (specific heat) are examined within the framework of the band model suggested by Friedel. It is shown that all available data are consistent with a reasonable density of states curve, and the qualitative features of that curve are in agreement with those deduced by Friedel from the properties of pure uranium. Attention is directed to the thermoelectric power of these alloys as a means of further defining the band parameters. Moreover, the thermoelectric power of some uranium alloys may be large enough to be of practical interest.

* On leave of absence from Michigan State University.

T10. Ultrahigh Vacuum Evaporation of Tin on Single Crystal NaCl Substrates. RICHARD W. VOOK, *IBM Research Laboratory.*—High-purity tin films have been made in ultrahigh vacuum by evaporation onto (001) faces of NaCl at liquid nitrogen temperature and 0°C. These films were allowed to warm to room temperature before they were removed from the vacuum system and examined by electron diffraction and electron microscopy. Single crystal and highly oriented polycrystalline films were obtained under different conditions. Single crystal films were obtained only when the substrate was at liquid nitrogen temperature and when cleaved surfaces and short successive evaporation times were used. Between the short evaporation the substrate was allowed to cool back down to liquid nitrogen temperature. If any of the following conditions existed, then the resulting film was polycrystalline: (1) substrate at 0°C, (2) polished and recrystallized (001) NaCl face, and (3) continuous evaporation of greater than about 10 sec. The evaporation rate of all the films was of the order of 50 A/sec, and the film thicknesses were in the range from about 1000 A to 2500 A. Grain growth in all the polycrystalline films could be made to occur with the electron beam in the electron microscope after incubation periods of from approximately 2 to 7 min.

T11. Characteristics of the Annealing Kinetics of Tin Films Deposited at 88°K. J. R. PRIEST, C. CHIOU, AND H. L. CASWELL, *IBM Research Laboratory.*—The electrical resistance of evaporated, high-purity tin films deposited at 88°K decreases rapidly in two distinct temperature regions as determined by isothermal annealing studies. One annealing peak occurs at 180°K and has an activation energy of 0.74 ± 0.10 ev which agrees closely with that required for vacancy migration in tin. The second peak at 112°K has an activation energy of 0.34 ± 0.06 ev which possibly could be associated with the migration of di-vacancies. The annealing characteristics of pure films varying in thickness from 410 A to 4200 A and a film deposited in a high partial pressure of N_2 are quite reproducible. The presence of O_2 during evaporation, however, drastically altered the annealing kinetics and increased the activation energy at any given temperature. The defect resistivity at the time of evaporation is independent of film thickness or the presence of N_2 but is about 75% higher for the film deposited in the presence of O_2.

SATURDAY AFTERNOON AT 1:30

Eckhart 133

(C. J. OVERBECK presiding)

Atomic and Molecular Physics

Invited Paper

U1. Use of a Scintillation Chamber in Bevatron Experiments on Pion Scattering. L. W. JONES, *University of Michigan.* (30 min.)

U2. Anticoincidence Gamma-Ray Spectrometer. S. RABOY, *Argonne National Laboratory.* (30 min.)

Contributed Papers

U3. Reflectivity of Diamond from 5.5 to 14.4 ev.* J. R. NELSON AND W. C. CROCKER, *Convair–San Diego Division.*—A large absorption peak is seen in the absolute normal incidence (5 deg) reflectivity of a large single crystal of diamond in the far ultraviolet. This peak is centered at 975 A (12.7 ev) with a half-width of about 3.5 ev. In addition, two peaks of very low magnitude are observed at 1725 A (7.19 ev) and 2000 A (6.2 ev). The structure thought to be seen in the previous work of Robin[1] down to 1400 A is doubtful because of an experimental precision of 20% compared with a precision of 1% in our work. There is an energy expanse of 7 ev between the absorption edge[2] at about 2220 A (5.6 ev) and the large absorption peak mentioned. The wide energy expanse of no pronounced structure is probably connected with the complicated band structure.[3]

* This research is supported in part by the Advanced Research Projects Agency through the U. S. Air Force Cambridge Research Center (AFCRC), Air Research and Development Command.

[1] S. Robin, Rev. optique **33**, No. 8 (August, 1954).
[2] J. F. H. Custers and F. A. Raal, Nature **179**, 268 (February 2, 1957).
[3] L. Kleinman and J. C. Phillips, Phys. Rev. **116**, 880 (1959).

U4. Scattering of 2–12 ev Electrons by Atomic Hydrogen.* R. H. NEYNABER, E. W. ROTHE, L. L. MARINO, AND S. M. TRUJILLO, *Convair–San Diego Division.*—The total cross sections for scattering 2–12 ev electrons by atomic hydrogen have been measured by a modulated molecular beam technique. The basic measurement compared the number of electrons scattered from a region defined by the intersection of an electron beam and a chopped molecular beam with the number scattered when the hydrogen beam was partially dissociated. By measuring the degree of dissociation with a mass spectrometer, one may obtain the ratio of cross sections of atomic and molecular hydrogen for a given energy. The absolute atomic values were calculated from these ratios and molecular hydrogen values obtained from the literature. The geometry of the experiment was such that most scattered electrons were detected and thus was more similar to a previous experiment of Bederson, Malamud, and Hammer[1] than that of

Brackmann, Fite, and Neynaber.[2] The results are compared with those two experiments and with theoretical estimates.

* Supported in part by the Advanced Research Projects Agency through the U. S. Army Rocket and Guided Missile Agency.
[1] B. Bederson, M. Malamud, and J. Hammer, Bull. Am. Phys. Soc. Ser. II, 2, 172 (1957).
[2] R. Brackmann, W. Fite, and R. Neynaber, Phys. Rev. 112, 1157 (1958).

U5. Te II Spectrum. SISTER M. BERNARDA HANDRUP,* *University of Wisconsin.*—Observed energy levels and g values of the two lowest configurations of TeII, $5p^3$ and $5p^26p$, are compared with levels obtained on an electronic computer with a code written by R. E. Trees. With only electrostatic and spin-orbit terms included in the calculation, the rms deviation for the five known levels of the ground configuration is $170K$; for the nineteen known levels of $5p^26p$ it is $630K$. The electrostatic and spin-orbit parameters used for the calculations are compared with those in 20 np^2 and 6 $np^2(n+1)p$ configurations in related spectra. The parameter values are shown to vary in a regular fashion with z and with the degree of ionization of the atom. From Zeeman effect plates made at the Oak Ridge National Laboratory by P. Griffin and K. Vander Sluis, accurate g values for 92 levels have been derived, and the forbidden transition $p^3\ {}^4S^0_{\frac{3}{2}}-{}^2P^0_{\frac{1}{2}}$ has been identified. The 42 odd and 66 even levels all have been assigned to configurations or to groups of interacting configurations. Thirty-one of them have been assigned $J'l$ or pair coupling classifications.

* Present address: Alverno College.

U6. Measurements of the Ultrasonic Absorption and Velocity in Molten Salts.* R. W. HIGGS, *Armour Research Foundation,* AND T. A. LITOVITZ, *Catholic University of America.*—Measurements[1] of ultrasonic absorption and velocity were made in the molten salts KNO_3, $NaNO_3$, $AgNO_3$, $LiNO_3$, $CdCl_2$, and $PbCl_2$ and the molten salt mixture $NaNO_3$-KNO_3. The results indicate that these molten salts exhibit a structural viscosity similar to that found in water and associated organic liquids. The ratio of the bulk to shear viscosity (η_b/η_s) ran as high as 10 in KNO_3 and as low as 1.03 in $PbCl_2$. In the Group I nitrates, the ratio η_b/η_s was found to be directly proportional to the volume of the cation. The $\ln\eta_b/\eta_s$ of the nitrates and chlorides was found to be a linear function of the entropy of fusion. Consideration of the ultrasonic data[2,3] in the primary alcohols showed that here also the $\ln\eta_b/\eta_s$ is a linear function of the entropy of fusion when considering an homologous series. These results indicate that the structural relaxation process in both the ionic and organic liquids involves considerable randomization of the quasi-crystalline liquid lattice.

* Supported by the Office of Ordnance Research.
[1] R. W. Higgs and T. A. Litovitz (to be published).
[2] J. W. Pellam and J. K. Galt, J. Chem. Phys. 14, 608 (1946).
[3] J. M. Pinkerton, Proc. Phys. Soc. (London) B, 62 (1949).

U7. Response of a Thermocouple Circuit to Nonsteady Currents. THOMAS T. ARAI AND JOHN R. MADIGAN, *Borg-Warner Corporation.*—The response of a thermocouple circuit functioning as a Peltier cooler to time varying currents was determined by assuming that the current density could be represented by the sum of a dc and a time varying component. The time varying component took the form of either an impulse applied at time $t_0>0$, a square pulse lasting from t_0 to t_1, a step increase in the current at time t_0, or a sinusoidal ripple superposed on the dc current. The increased current results in an initial thermal cold spike at the cold junction, but the time average temperature between the junctions is reduced unless the dc current is well below the optimum value. The possibility of using such thermal spikes in a vary long wavelength infrared communications system or in synchronous detection is discussed. In the case of a sinusoidal ripple the temperature difference between the junctions either may follow the fluctuations in current or may not depending on the time constant of the couple and the frequency of the ac signal. In the latter case the only effect is a reduction in the temperature difference between junctions by the additional Joule heating due to the ac component.

U8. Rate Equations for Constituents of Slightly Ionized Chemosphere.* CARSTEN M. HAALAND, *Armour Research Foundation.*—Reactions of the chemosphere (30–200 km) have been investigated to determine the role of various minor constituents such as NO_2 and O_3 in the electron loss process following ionization by a solar event. Electron recombination, with positive ions, attachment to electronegative particles, charge transfer, charge neutralization between positive and negative ions, collisional detachment, photodetachment, -dissociation and -ionization (NO^+ primarily) have been represented in a set of nonlinear first-order differential equations. Some specific charge exchange reactions of importance are discussed in detail. Results of an investigation with a simpler model (NO omitted) on the effect of variation of the rate coefficients within their error limits on the electron density show that for a strong constant source of ionization the extreme variation of the coefficients has little effect on the electron density, while with a weak source of ionization the calculated electron density is highly sensitive to the choice of rate coefficients.

* Work supported by the U. S. Signal Corps.

SATURDAY AFTERNOON AT 1:30

Social Sciences 122

(G. WENTZEL presiding)

Theoretical Physics

V1. Possible Violation of the Second Law of Thermodynamics: the Statistics Aspect. PETER FONG, *Utica College of Syracuse University.*—A possible violation of the second law of thermodynamics and a reformulation of thermodynamics have been reported.[1] A gas of charged particles under the action of a uniform magnetic field is separated into two containers connected by a curved tube, the curvature of which is so adjusted that only charged particles of a high energy may pass from one container to the other. These particles cannot go backward through the tube because of the fact that when the velocity is reversed the force $(q/c)\mathbf{V}\times\mathbf{B}$ is reversed, and therefore the curvature of the trajectory is reversed. The gas in one container becomes cooler and rarer while the other becomes hotter and denser; the second law thus seems to be violated. Objection has been raised concerning the possibility that the particles getting through the tube by collisions with the tube

wall may compensate this effect. Calculations have been carried out which show that under the assumption of random reflection of the colliding particles at the tube wall the particles getting through the tube by collisions seem to reinforce, rather than to compensate, this effect.

[1] Peter Fong, Post-Deadline Paper P15, Washington Meeting of the American Physical Society, April, 1960.

V2. Spin Density Wave States of an Electron Gas. A. W. OVERHAUSER, *Ford Motor Scientific Laboratory.*—The Hartree-Fock equations for a (three-dimensional) electron gas have been solved without the use of perturbation theory, taking into account the repopulation of k space caused by the spatially periodic self-consistent exchange potential associated with a static spin density wave (SDW).[1] SDW eignestates always exist for every wave vector $\mathbf{q}$ satisfying $0<q<2k_F$. The limits $q=0$ and $q=2k_F$ correspond to the usual ferromagnetic and paramagnetic states, respectively. For typical electron densities the Hartree-Fock ground state is a SDW state. Correlation energy corrections are smaller for a SDW state than for the paramagnetic state, so that unequivocal predictions regarding the character of the true ground state cannot be made on a theoretical basis. On the other hand, correlation energy corrections are smaller for the ferromagnetic state than for a SDW state. Therefore, ferromagnetism of an ideal electron gas is less likely than SDW antiferromagnetism. In any event, there is a continuous spectrum of SDW excited states for a repulsive Fermi gas, whether the interactions are short range, long range, strong, or arbitrarily weak. This subset of all possible excited states extends continuously to the ground state, whether that state is paramagnetic, ferromagnetic, or SDW antiferromagnetic. These conclusions are not subject to any quantitative criterion, repulsive interactions being the only requirement.

[1] A. W. Overhauser, Phys. Rev. Letters **4**, 462 (1960).

V3. Relativistic Dynamics and Newtonian Causality.* PETER HAVAS AND JERZY PLEBANSKI,† *Lehigh University.*—In Newtonian dynamics the motion of a system of particles is determined by the equations of motion together with the initial positions and momenta. It is widely believed that in relativity the existence of a maximum signal velocity precludes the possibility of a determination of the world lines of the particles by a similar specification of initial data. Closer analysis shows that the requirements of special relativity do not exclude such a possibility.[1] However, earlier investigations had not succeeded either in establishing that previously known equations of motion (such as Fokker's formulation of electrodynamics) possess Newtonian causality or in exhibiting new equations possessing this property (except by abandoning the concept of invariant world lines[2]). For the case of two bodies we have found several types of equations of motion for which this property has been proved. Their relation to previously known equations will be discussed.

* Research supported by the National Science Foundation and the Air Force Research Division, ARDC, U. S. Air Force.
† Permanent address: University of Warsaw.
[1] See, e.g., P. A. M. Dirac, Revs. Modern Phys. **21**, 392 (1949).
[2] B. Bakamjian and L. H. Thomas, Phys. Rev. **92**, 1300 (1953).

V4. Perturbation Energy Coefficients and Ionization Potentials of the Three- to Ten-Electron Isoelectronic Ionic Series.* CHARLES W. SCHERR, JEREMIAH N. SILVERMAN, AND F. A. MATSEN, *University of Texas.*—A method for recovering the second- and higher-order nonrelativistic perturbation energy coefficients of atomic systems directly from experimental energies is described. The experimental values of the ionization potentials are first corrected for relativistic effects. The relativistic corrections are obtained by modifying Dirac one-electron theory and the lowest order one-electron radiative shift with experimentally derived shielding parameters. The theoretically obtained zero- and first-order nonrelativistic energy contributions are then removed from the corrected ionization potentials, and the remainder is multiplied by Z^p, where Z is the nuclear charge. The resulting polynomial is differenced p times to recover the second-order energy coefficient which is contaminated with the $(p+3)$th and the higher-order coefficients. The optimum value of p depends upon the quality and quantity of the experimental data available. The second-order energy contribution is then removed and the process repeated to recover the third-order contribution, etc. This method has been applied to the 3- to 10-electron isoelectronic ionic series. The perturbation coefficients thus obtained have been used to construct a set of nonrelativistic and "experimental" ionization potentials for each of these series through $Z=20$. Several gaps are filled and inaccuracies are disclosed in existing data. In addition, estimates of electron affinities of negative ions are obtained.

* This research was supported in part by the Robert A. Welch Foundation and the Office of Ordnance Research, U. S. Army.

V5. Analytical Methods in Hartree-Fock Self-Consistent Field Theory.* S. HUZINAGA, *University of Chicago* (introduced by R. S. Mulliken).—Two alternative schemes are proposed for the determination of electronic self-consistent field (SCF) orbitals in atoms and molecules. They are designed to be applied principally to the electronic configurations consisting of two open shells. Both schemes are based upon the idea that the SCF orbitals are expanded in terms of adequate basis functions, but they are different from each other in the way of solving the SCF problem. The first one is a straightforward extension of Roothaan's theory[1] and the second one is a more radical modification of the procedure adopted in Roothaan's theory.

* Supported by the Office of Naval Research.
[1] C. C. J. Roothaan, Revs. Modern Phys. **32**, 179 (1960).

V6. Perturbation Theory of Many-Electron Atoms and Molecules. OKTAY SINANOĞLU, *Yale University.*—Perturbation theory is applied with operator techniques to a nondegenerate many-electron system, taking the entire interelectronic repulsions,

$$\sum_{i>j}^{N} r_{ij}^{-1},$$

as perturbation. The first-order wave function (WF), X_1 of the N-electron system, is obtained rigorously in terms of the similar first-order WF's of actual, independent two-electron systems. The WF's of these electron pairs can be obtained individually and with explicit dependence on nuclear parameters from two-electron nonhomogeneous differential equations or equivalent variational principles. A set of such pair functions then may be used to build up different atoms or molecules. For example, Li atom is built up entirely from the $(1s)^2$ ^1S, $(1s2s)$ ^1S, and ^3S states of Li^+ ion; Be atom requires in addition to these only the $(2s)^2$ ^1S pair state. The X_1 gives the energy to third order and as an upper limit to the exact E. The second-order energy is equal to the sum of pair interactions plus many-body terms of two types: (a) "cross polarization" which exists even in no exchange intermolecular forces, and (b) 3- and 4-body Fermi correlations. This theory extends the shell concepts of molecular quantum mechanics so as to include electron correlation.

V7. Oscillator Strengths as Criteria of H_2^+ Approximate Wave Functions. CHRISTIAN WAHL AND S. J. EHRENSON, *University of Chicago* (introduced by R. S. Mulliken).—The H_2^+ system is used in a study of oscillator strengths employing the dipole length, velocity, and acceleration operators. A very good approximation[1] to the exact ground state wave function is used with various types of approximate excited state func-

tions. The parameters of the excited state functions are varied, and electron distribution of the excited state is correlated with the variations and divergence of Q_L, Q_V, and Q_A, Q's containing appropriate energy factors ($Q_L=Q_V=Q_A$ if both wave functions are exact[1]). The stringency of the convergence of Q_L, Q_V, and Q_A values as a criterion for the "goodness" of an approximate wave function is investigated.

[1] The best ground state function of Dalgarno and Poots, Proc. Phys. Soc. (London) **A67**, 343 (1954).
[2] Cf. Bethe and Salpeter, *Encyclopedia of Physics* (Springer-Verlag, Berlin, 1957), Vol. XXXV, p. 334.

V8. Bound Pairs and Elimination of Reaction Matrix Singularities. RICHARD L. BECKER, *Oak Ridge National Laboratory.*—It is shown that in a careful treatment of the independent pair model the energy shift for a pair differs in the limit of an infinite system from the corresponding reaction matrix element by a normalization factor and, unlike the latter, does not have singularities. In place of the nonexistent singular continuum state there is a positive energy bound state solution of the Bethe-Goldstone equation. The existence of true bound states imbedded in the continuum is a consequence solely of the Pauli principle. The positive eigenstates must lie lower than the unperturbed state of momentum p_F-P where p_F is the Fermi and P the center-of-mass momentum. Bound states correspond to "molecule" formation in a medium. Negative energy ones exist for a combination of sufficiently strong attraction, low density, and low center-of-mass momentum. The eigenvalue is not inversely proportional to the volume and so may contribute non-negligibly to the binding energy. However, for a bound system (e.g., nucleus) the density increases with the attraction in a way which may prevent negative energy pair states. As illustrations, two one-dimensional examples are worked out in detail.

V9. On the Quadrupoles in Lighthill's Theory of Jet Noise.* E. G. GRIMSAL, *Armour Research Foundation.*—The Lighthill theory of aerodynamic noise utilizes the concept of an artificial source operating in an artificial acoustic medium, the expression for the source being obtained by rewriting the equation of motion for a Navier-Stokes gas so that one part is the acoustic wave equation and then considering the remaining terms as the source. The far-field of this artificial source is calculated from the Kirchoff volume integral. In any application of the theory the limiting factor is the lack of knowledge of the source terms; in applying the theory to jet noise, Lighthill has approximated the sources by moving quadrupoles. However, as will be shown, analyses of the Kirchoff integral and of the structure of the jet show that the convected quadrupole approach is too simple and overestimates the effect of convection on the radiated acoustic power.

* This research was supported by the U. S. Air Force, Wright Air Development Division.

V10. Mass Systematics and Assemblage Theory. RUSSELL G. HERRON, *U. S. Naval Nuclear Ordnance Evaluation Unit, Albuquerque.*—An assemblage theory of matter which depicts elementary particles and atomic nuclei as composite assemblages of more simple point configurations is presented. The masses of all mesons, hyperons, and ground-state nuclei with A less than 34 are calculated accurately within experimental error by use of a heuristic mass formula containing four quantized parameters. All particles observed to date are explained by the theory, which, in addition, predicts certain new particle configurations. Neutrons and protons are shown to be different states of the same baryon assemblage. The rest mass of the electron is calculated to be 548.7674169×10^{-6} amu. The calculated masses of eighty-four isotopes with A less than 34 are reported in figures of 10^{-8} amu with an average algebraic deviation from experimental data of less than 10^{-7} amu. Within this group, unreported nuclear spins are predicted for the ground state of thirty-five isotopes. It is concluded that the mass states of all particles are quantized and that all particles can be represented by the point conservation model of assemblage theory.

V11. Harmonious Principles in the Composition of Crystalline Silicates. NICHOLAS EFREMOV, *600 West 142nd Street, New York, New York.*—One of the very characteristic and typical features of the chemical composition of silicates can be designated as a manifestation of unity in diversity. This unity in diversity emerges during the entire development of the initial ancestor magma into crystalline matter consisting of highly differentiated magmatic rocks in which we observe similar equivalent ionic complexes in the composition of rock-forming minerals. Especially striking is the presence of equivalent ionic complexes in which valence numbers are a harmonic series of numbers (i.e., 4, 8, 12, 24, 48). By using these harmonious regularities and combining these "rockforming" ionic complexes, we hypothetically obtain the formulas of typical silicates (Table I). These precalculated *a priori* formulas

TABLE I.

Silicates	Ionic complexes				
Paragonite	H_4	Na_2Al_2	Al_4	Si_8	O_{24}
Muscovite	H_4	K_2Al_2	Al_4	Si_8	O_{24}
Phlogopite	H_4	K_2Al_2	Mg_6	Si_8	O_{24}
Valences	4	8	12	24	48
Valence relations	1	2	3	6	12

exactly correspond to the actual formulas of existing silicates such as typical mica-muscovite, phlogopite, paragonite, etc. From that regularity it appears that the basic elements of musical harmony and the principles of the chemical composition of silicates are very similar.

SUPPLEMENTARY PROGRAMME

SP1. Variation—Perturbation Method for Excited States.* OKTAY SINANOĞLU, *Yale University.*—The first-order wave function X_1 of the usual perturbation method can be obtained by a variational principle instead of summing over the infinite set of unperturbed eignefunctions with a large continuum contribution. For a ground state or for the lowest state of given symmetry type, X_1 is approached by choosing suitable trial functions $\bar{X}_1$ to attain $E_2[\bar{X}_1]$ as a minimum. Hylleraas obtained good results by this method on the ground state of He-like ions. A minimization method is developed by the writer to evaluate the X_1 of any excited state m, regardless of its symmetry. E_2 is obtained as a minimum, if the excited state trial functions are subject to some restrictions. These restrictions require a knowledge of only the *unperturbed* eigenfunctions of the states below m, unlike in the ordinary variation method where *exact* eigenfunctions would be needed. The X_1 gives also the third-order energy. The method may be applied to such excited states as $(1s2s)\ ^1S$ of the He-like ions and to the similar electron pairs that arise in the theory of a many-electron atom or molecule developed by this writer.

* To be given at the end of Session V if the Chairman rules that time permits.

SP2. Microwave Acoustic Absorption at Low Temperatures.* H. E. BÖMMEL AND K. DRANSFELD, *Bell Telephone Laboratories, Inc.*—We have measured the absorption of longitudinal and transverse acoustic waves in crystalline quartz at a frequency of 10^{10} cps and at temperatures below 20°K. For longitudinal waves an X-cut quartz was used (sound velocity $v=5.6\times10^5$ cm/sec), and for transverse waves an AC-cut crystal ($v=3.3\times10^5$ cm/sec). We used a long effective path length by observing an appreciable number of echoes and found the absorption of longitudinal waves to vary with temperature as T^9 but only with T^4 for transverse waves. The frequency dependence between 10^9 cps and 10^{10} cps is less than linear in both cases. The different temperature dependence is not compatible with Akchiezer's description. It rather supports the assumption[1] that longitudinal phonons cannot relax by 3-phonon collisions but need 4-phonon processes in order to conserve energy and momentum, leading to the rapid observed temperature variation. Since transverse phonons can relax by 3-phonon processes, the temperature dependence is correspondingly smaller. Our data for longitudinal waves above 20°K agree with results by Jacobson.[2]

* To be given at the end of Session I if the Chairman rules that time permits.

[1] See, for example, Landau and Rumer, Phys. Z. Sowjetunion **11**, 18 (1937).

[2] Jacobson, *Quantum Electronics* (1960), p. 468.

SP3. Course Concept in High-Energy Particles.* JOSEPH G. BARREDO, *C.S.I.C.*—Margenau, Mould, Dingle, and Barredo[1] demonstrated that relativity and electrodynamics have internal inconsistency because dx is undefined. Thus, by requiring consistency with relativity, field theory fails to explain or even classify the galaxy of "elementary particles." Elementary particles are neither elementary nor particles but an all-body problem to be resolved through triondynamics. Triondyanmics defines

$$dx \text{ by } dx/dt = N^{\frac{2}{3}}t^{-\frac{1}{3}}, \qquad (1)$$

where N = number of charges, t = time. Equation (1) demonstrates: (1) the concept of particle, observable, derivative, and the chronosuperconductivity effect are identical; (2) any observable is a high-energy phenomenon when observed with devices of rise-time sufficiently small; (3) the recently found chronosuperconductivity effect in photosynthesis is a particular case of triondynamics; (4) the trion concept improves Galileo's definition of cause because the rest of the universe acts upon the three charges forming the trion, and still the trion's formation is a necessary and sufficient condition of observability.

* To be given at the end of Session Q if the Chairman rules that time permits.

[1] H. Margenau and R. A. Mould, Phil. Trans. Roy. Soc. (London) **24**, 297 (1957); H. Dingle, Nature **183**, 1761 (1959) and Phil. Trans. Roy. Soc. (London) **27**, 233 (1960); J. G. Barredo, Naturwissenschaften **15**, 346 (1956) and Bull. Am. Phys. Soc. Ser. II **5**, 365 (1960).

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Second Announcement of the 1960 December Meeting in Berkeley

The 1960 winter meeting in the West will be held in Berkeley on the campus of the University of California, with the Department of Physics acting as host. The days of Thursday, Friday, and Saturday, December 29, 30, and 31 are reserved for the usual presentation of 10-min papers and invited papers. You are reminded that the deadline date for abstracts is October 14, which is the date by which abstracts must be in the office of the Deputy Secretary for the Pacific Coast, Professor E. L. Hahn, Department of Physics, University of California, Berkeley 4. On Thursday, December 29, the regular meeting will overlap with the special topical conference on Strong Interactions, which is discussed in a separate announcement in this Bulletin.

Blocks of rooms have been reserved for both the regular meeting and the Strong Interaction topical conference at hotels Shattuck, Durant, and Claremont, and at motels Berkeley Plaza, Berkeley Travelodge, California, and Berkeley Flamingo. Please note that December 15 is the deadline date for reservations of the above accommodations; after that date, you are on your own like any other tourist. Reservations must be written for directly, making it clear that you are attending the Berkeley meeting of the American Physical Society. Those who prefer to stay in San Francisco will find relatively convenient bus service from San Francisco to Berkeley. Rooms in Berkeley should be reserved as soon as possible, and probably some sharing of rooms will be necessary.

There will be a cocktail party and banquet of the Society on Friday, December 30, in the Hotel Claremont.

Invited sessions at the meeting will cover such topics as astrophysics and cosmic rays, theoretical and nuclear physics, solid-state physics, and experimental biophysics.

Announcement of the Conference on Strong Interactions to Be Held in Berkeley, California, December 27, 28, 29

In connection with the 1960 winter meeting of the American Physical Society in Berkeley on Thursday, Friday, and Saturday, December 29, 30, 31, a special conference on Strong Interactions will be held in Berkeley on Tuesday, Wednesday, and Thursday, December 27, 28, and 29. The meeting will be an open one and will be held in LeConte Hall, the Department of Physics building, on the Berkeley campus.

The meeting will consist of invited papers with ample time for a discussion both inside and outside of the regularly scheduled sessions. There also will be time to visit the Lawrence Radiation Laboratory. The first two days will be devoted to the more experimental aspects of strong interactions and probably will be divided among pions, K mesons, and baryons. On the third day, and simultaneously with the first day of the regular Pacific Coast meeting of the Physical Society, the theoretical aspects of strong interactions will be reviewed. There will be no contributed papers at these meetings.

Physical arrangements for the conference are discussed in the announcement for the Berkeley meeting, given above on this page.

The committee in charge of this conference consists of V. F. Weisskopf, W. K. H. Panofsky, R. L. Cool, G. F. Chew, D. A. Glaser, and A. C. Helmholz, *Chairman*. Inquiries should be addressed to A. C. Helmholz, Department of Physics, University of California, Berkeley 4.

Preliminary Announcement of the 1961 Annual Meeting

The 1961 Annual Meeting of The American Physical Society will be held in New York City on Wednesday, Thursday, Friday, and Saturday, February 1, 2, 3, and 4, 1961. As usual, The American Association of Physics Teachers will hold concurrent sessions and there will be a joint ceremonial session of the two societies comprising the APS retiring Presidential address and the AAPT Richtmyer lecture and Oersted Prize presentation.

There will be a business meeting of our Society. The official hotel for the meeting will be the New Yorker (New York 1, New York). It is advisable to make your reservations for this meeting as early as possible. You should write to the Hotel New Yorker and mention that you are coming to a meeting of the Society.

The scientific sessions for the meeting will be held in or near the Hotel New Yorker.

Deadline day for the meeting is November 11. Abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

Preliminary Announcement of the 1961 March Meeting in Monterey

The 1961 March meeting will be held at the U. S. Naval Postgraduate School, in Monterey, California, on Monday, Tuesday, and Wednesday, March 20, 21, and 22. A fourth day, March 23, will be taken up by sessions of the Division of High-Polymer Physics. The Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics will feature sessions during this meeting.

Accommodations will be available at the following hotels: Mark Thomas Inn and Casa Munras. Motel rooms will also be available in the area. Members are urged to write as soon as possible for room reservations to the Monterey Peninsula Convention Bureau, P. O. Box 1571, Monterey, who are acting as agents. Be certain to state that you are attending the meeting of The American Physical Society.

Abstracts for the meeting should reach the office of the Deputy Secretary for the Pacific Coast, Professor E. L. Hahn, Department of Physics, University of California, Berkeley 4, no later than January 13, 1961.

1961 Meeting of the Division of High-Polymer Physics

The Division of High-Polymer Physics will convene at Monterey, California, at the regular meeting of the Society on March 21 and 22 with additional sessions on March 23. Abstracts for this Divisional meeting should be sent to Dr. David W. McCall, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey, and must be received in Dr. McCall's office by Friday, January 6, 1961. This date is one week in advance of the deadline for the regular meeting of the Society. The abstracts for the Divisional meeting must conform to the same regulations as are imposed on those submitted for general meetings of the Society.

ANNOUNCEMENT—*The Physics of Fluids*

The American Institute of Physics announces that *The Physics of Fluids* will be published monthly, instead of bimonthly, effective with Volume IV (1961). The journal is devoted to reporting the results of research on the structure, statistical mechanics, and general physics of gases, liquids, plasmas, and other fluids. As before, the journal will continue to offer papers on certain basic aspects of physics of fluids bordering geophysics, astrophysics, and related fields.

Proceedings of the American Physical Society

MINUTES OF THE MEETING OF THE SOUTHEASTERN SECTION HELD AT GATLINBURG, TENNESSEE, APRIL 7, 8, AND 9, 1960

THE twenty-sixth meeting of the Southeastern Section of the American Physical Society, held in Gatlinburg on April 7, 8, and 9, 1960, was attended by about 400 physicists from the region. The arrangements at Gatlinburg were made by J. L. Fowler and his committee with the Oak Ridge National Laboratory acting as host. The program was planned by another committee chaired by H. W. Lewis. The program of 17 invited and 84 contributed papers appears below. Titles of 6 invited lectures and 12 additional papers related to physics teaching are recorded in the *American Journal of Physics*. The dinner address was given by R. J. Seeger, National Science Foundation. During the meeting the Section chose the University of Louisville, Louisville, Kentucky, as the site of its 1961 meeting on March 30 and 31 and April 1. The Section also elected the following as its officers for 1960–1961; J. L. Fowler, Oak Ridge National Laboratory, *Chairman*; Ingram Bloch, Vanderbilt, *Vice-Chairman*; Howard Carr, Auburn University, *Secretary*; Myron McCay, University of Chattanooga, *Treasurer*; and A. P. French, University of South Carolina, and L. D. Wylie, Georgia Institute of Technology (appointed for one year), *Executive Committeemen*. L. W. Cochran, University of Kentucky, is retiring Chairman.

HOWARD CARR, *Secretary*
Southeastern Section
American Physical Society

Instrumentation

Invited Paper

A1. Semiconductor Charged Particle Spectrometers. J. L. BLANKENSHIP, *Oak Ridge National Laboratory.*

Contributed Papers

A2. Oak Ridge Isochronous Cyclotron. R. S. LIVINGSTON AND R. J. JONES, *Oak Ridge National Laboratory.*—A cyclotron of unusually high performance and flexibility is under construction at ORNL. Energy variation is achieved through an rf system which can operate at any desired frequency below 22.5 Mc/s with the radio-frequency being either the fundamental or a harmonic of the frequency of the revolving particle. Focusing of the particles and isochronism between the rf voltage and the particle angular velocity are maintained by a suitably shaped three-sector magnetic field supplied with numerous and powerful trimming windings. The cyclotron is housed in a building which includes necessary laboratory and office space for the research staff. Three concrete vaults are provided, one for the cyclotron and two for experimental nuclear physics. Provision is made for the installation of a 12-ft diam analyzing magnet rotating on a heavy gun mount. It is planned to accelerate protons up to 75 Mev; deuterons, 39 Mev; helium-3, 100 Mev; helium-4, 78 Mev; carbon-12^{4+}, 115 Mev; nitrogen^{4+}, 100 Mev; oxygen-16^{4+}, 88 Mev; and argon-40^{7+}, 103 Mev.

A3. Radio-Frequency System for ORIC. R. E. WORSHAM, S. W. MOSKO, AND N. F. ZIEGLER, *Oak Ridge National Laboratory.*—To accelerate particles to the energies described in the previous paper the rf system for ORIC must be able to tune to any frequency in the 7.5- to 22.5-Mc/sec range and produce 200-kev energy gain per turn (protons). The resonator consists of a single 180° dee as part of a coaxial quarter-wave resonator. Tuning is accomplished with a movable plunger, or shorting plane, and with trimming capacitor plates along the dee periphery. The dee, 70 in. in diameter spaced 1.5 in. from the liner, is connected through a tapered transition section to a 50-in. diam cylindrical dee stem surrounded by a 75-in. diam outer conductor, or housing. The 48-segment shorting plane can be moved 130 in. Under full load conditions, 300 kw will excite the resonator at 22.5 Mc/sec with 100-kv peak dee voltage and 75-kw beam power. An RCA-6949 tube will be coupled capacitively to the dee. Its plate voltage will be controlled by a series regulator tube on the plate power supply to hold the peak dee voltage constant to about 1 part in 10^3. An oscillator in the console will generate the frequency and autotune control signals.

A4. Magnetic Field Design and Orbit Calculations for ORIC. R. S. BENDER, R. H. BASSEL, AND T. C. SHEARIN, *Oak Ridge National Laboratory.*—To design a suitable magnetic field for a variable-ion, variable-energy AVF cyclotron it has been necessary to perfect a complex set of programs for the IBM-704 computor. A technique is being developed for inserting a realistic electrostatic deflector and a magnetic channel for deflection studies. In addition, the effects of the rf voltage on starting conditions are being added to the orbit computations. With the use of the orbit programs now available, quantitative luminosity studies can be made. The results of model magnet studies will be shown. The critical features of the magnetic field, where it is either impractical to shape the field as desired or conflicting requirements are imposed by different conditions such as isochronism and deflection, will be discussed. Emphasis will be on present status and on problems still to be solved in the magnet design.

A5. Magnetic Measurements for ORIC. E. D. HUDSON AND R. S. LORD, *Oak Ridge National Laboratory.*—To provide data for the computing program described in the previous paper,

measurements are being made on a ¼-scale model of the ORIC magnet. The over-all reproducibility of the measurements including probe positioning and magnet excitation drift is ±0.02% of the maximum field. The data are automatically logged on perforated paper tape for direct input into a digital computer. The measuring system consists of a precision positioning gear, Hall generator as the sensing element, preamplifier, scanner, digital voltmeter, tape perforator, and a printer. The system is self-calibrated prior to logging each data point so that drift in the instruments can be compensated in the computing program. The inherent 0.06% per °C temperature coefficient of the Hall generator is compensated by a thermistor so that the output voltage is constant to ±0.01% over a range of 10°C. A 2400-point scan is completed in less than 12 hr.

A6. Polarized Ion Source. J. E. SHERWOOD, S. J. OVENSHINE, AND R. F. KING, *Oak Ridge National Laboratory.*—A source of polarized ions (H^+ and D^+) is under construction at ORNL. The apparatus consists of a Rabi-type atomic beam machine which selects atomic hyperfine states having similarly oriented nuclei. These atoms are then passed through an electron bombardment ionizer. Hydrogen gas is used at present; however, it is planned to use deuterium gas and to test for polarization of the ions by means of the $T(d,n)He^4$ reaction at 100 kev, as proposed[1] by Galonsky *et al.* Preliminary measurements indicate 50% dissociation and an ionizer yield of 1 ion per 2000 atoms.

[1] A. Galonsky, H. B. Willard, and T. Welton, Phys. Rev. Letters **2**, 349 (1959).

A7. Source of Pulsed Neutrons. L. S. ANTHONY, J. S. MCCLURE,* AND ANDREW ROBESON, *Virginia Polytechnic Institute.*—A Cockcroft-Walton accelerator to produce neutron pulses of moderately high intensities has been built at Virginia Polytechnic Institute. The high voltage supply, a continuously variable voltage doubler circuit,[1] will deliver a maximum of 2 ma at 250 kv. Neutrons are produced using the $D(d,n)He^3$ reaction and pulses obtained by sweeping the deuteron beam from an rf ion source across the exit port with electrostatic deflection plates.[2] The entire system is mounted on casters to provide a reasonable degree of mobility. A single-channel variable-gate timing circuit, triggered by a pulse from the target, is used to measure time-dependent neutron intensities in moderator materials. A fast twenty-channel system is under construction. Experiments are under way to verify time-dependent neutron distributions predicted by Monte Carlo computations on an IBM 650 computor.

* U. S. Atomic Energy Commission Fellow in Nuclear Science and Engineering.
[1] Beta Electric Corporation.
[2] J. H. Neiler and W. M. Good, *Fast Neutron Physics* (Interscienec Publishers, Inc., New York), Chap. IV.

A8. Electron Current Integrator.* R. L. HOOVER AND LARRY W. BROWN, *The University of North Carolina.*—An accurate negative current integrator for use with our new Van de Graaff machine is described. A vacuum tube Type 6AR8 is used with a capacitor. The capacitor placed across the beam target to ground is allowed to charge to a predetermined voltage which allows the electronic circuit to short the capacitor in a manner similar to H. A. Enge's positive integrator. The integrator and cathode follower circuits for scaler operation are outlined. The instrument is easily converted to positive current service. The sensitivity of the instrument is well below 1 μcoul.

* This work was supported by the U. S. Atomic Energy Commission.

A9. Low-Energy Beta-Ray Studies with a Proportional Counter. PAUL E. SHEARIN AND R. L. HOOVER, *The University of North Carolina.*—A large proportional counter suitable for measuring radioactive gases is described. The counter is capable of resolving line spectra below 200 ev. The cathode of the counter is made of wires to reduce background and is surrounded by a ring of 9 anti-coincidence counters which use the common cathode of the main counter. The anti-coincidence counters permit accurate measurements of ionizing events which take place completely within the volume of the main counter by rejecting events which originate in the main counter and end beyond the cathode or those events which originate beyond the cathode and end within the counter volume. The main counter anode is divided into a short and long section to minimize end effects. The short section data is subtracted from the long section data. Preliminary results for the low-energy spectra of Cl^{38} and C^{14} and the electron capture of A^{37} are presented.

A10. Phase and Amplitude Variations in WWV Audio Signals. W. D. RICE AND L. W. MORRIS, *Louisiana State University.*—A locally constructed secondary frequency standard employs a GT-cut vacuum-mounted 100-kcps quartz crystal excited in a Meacham bridge. It is used to synchronize a decade frequency divider, composed of cathode coupled multivibrators, which in turn drives a 50-cps clock. Occasional abrupt changes in clock rate were related to loss of synchronization in certain stages of the multivibrator. Use of tuned LC circuits removed this difficulty. The amplified 50-cps output is also used to drive the helix of an Alden type 9094 recorder. One application of this equipment has been a preliminary study of the received WWV audio-frequency signals, including their abrupt phase shifts as ionospheric conditions change. Simultaneous recording of the amplitude variations in the received signal was made possible by the construction of a voltage-to-time translator which permitted recording of the AVC voltage of the receiver. The motion of the recorded seconds pulses relative to the zero-voltage base line affords a method of adjusting the rate of the crystal.

A11. Improved Instrument for Charged Particle Discrimination.* J. A. BIGGERSTAFF, R. F. HOOD, AND M. T. MCELLISTREM, *University of Kentucky* (introduced by B. D. Kern).—The separation of different types of charged reaction products has been achieved in a CsI (Tl) scintillation detector.[1] The separation depends upon observed differences in fluorescent decay rates. An improved version of this instrument has been developed and tested with the products of the Be^9+d reactions and with the protons from the $C^{12}(d,p)C^{13}$ reaction. Results of the tests indicate that protons, tritons, and α particles are clearly separated from one another by their decay time differences. The decay time separation of the α particles and protons is six times the instrumental resolution of the α particles, and the triton-proton separation is twice the instrumental resolution of the protons for $E_\alpha \sim 4$ Mev, $E_p \sim 3$–5 Mev, and $E_t \sim 3$ Mev. Operation of the instrument to permit study of the $Be^9(d,\alpha)$ reactions in the presence of the $C^{12}(d,p)C^{13}$ protons will be shown.

* Partially supported by the U. S. Atomic Energy Commission.
[1] R. L. Becker and J. A. Biggerstaff, Bull. Am. Phys. Soc. Ser. II, **4**, 326 (1959).

A12. Simplified Multichannel Time Analyzer in the Microsecond Range. A. J. GROSS AND W. Y. EPLING, *North Carolina State College* (introduced by Arthur W. Waltner).—A 26-channel time analyzer is described for measurement of mean lives of the order of 10^{-3} to 10^{-6} sec. Simplicity in electrical and mechanical design is emphasized. The circuit utilizes standard Burroughs 6700 Magnetron Beam Switching tubes as gate generators. The switching tubes are connected in cascade, with nine channels available from each tube, and are driven by a pulsed LC oscillator of frequency required to give the desired channel width. A univibrator triggered by the primary timing

reference signal is used to pulse the selected oscillator "on" for a time somewhat greater than the sum of the 26-channel widths, after which a blocking oscillator resets the circuit to the zero (unused) position to await another cycle of operation. The even and odd switching grid signals are obtained from amplitude discriminators connected to the output of a paraphase amplifier. The discrimination level is used to balance even and odd channel widths. The gating circuits are conventional dual cathode follower triode gates. Additional channels may be added by increasing the number of beam switching tubes without major circuitry changes.

A13. Measurements of the Longitudinal Polarization of Beta-Rays.* N. S. KENDRICK, JR., C. H. BRADEN, E. T. PATRONIS, JR., L. D. WYLY, *Georgia Institute of Technology.*—A description of an experimental apparatus and methods employed in the measurement of the longitudinal polarization of beta rays arising in the beta-decay process will be presented. The design of the experiment is similar in principle to that of Cavanagh *et al.*[1]

* Supported in part by a grant from the National Science Foundation.
[1] Cavanagh, Turner, Coleman, Gard, and Ridley, Phil. Mag. **2**, 1105 (1957).

Theoretical Physics and Nuclear Physics

Contributed Papers

C1. Rainbow Scattering of Heavy Ions. A. ZUCKER, *Oak Ridge National Laboratory.*—A semiclassical scattering theory recently proposed[1] that the elastic scattering of α particles from nuclei may be treated analogously to the scattering of electromagnetic radiation from water droplets. In particular a singularity in the classical cross section which causes rainbows may be used to explain the nuclear elastic scattering cross section on the dark side of the rainbow. The theory employs two free parameters related to a nuclear interaction distance R and to a nuclear surface thickness ΔR. This theory has been applied to the case of elastic scattering of heavy ions from various nuclei and shows that for the interaction distance $R=r_0(A_1^{\frac{1}{3}}+A_2^{\frac{1}{3}})$ the value of $r_0=1.5\pm0.1$ f is compatible with the data over a wide range of energy and atomic number of the target. The surface thickness ΔR appears to be approximately $\Delta R=0.1R$, again for many energies and values of the atomic number.

[1] K. W. Ford and J. A. Wheeler, Ann. Phys. **7**, 259–322 (1959).

C2. On Problems Converse in Boundary Value Problems. ALBERT MASKET, *University of North Carolina.*—It is demonstrated by means of the Operational Calculus how time-dependent boundary conditions for a given region or medium may be determined from a knowledge of time-dependent interior values of the variable function over a minimum of interior positions of the region. Selected problems from the classical cases in vibration and heat conduction will be presented. These dispose of the simpler problems with plane, line, and point geometry. The relaxation of geometrical simplicity leads to mathematical complications which will be discussed in a problem in cylindrical geometry.

C3. Spherical Gravitational Waves. IVOR ROBINSON, *University of North Carolina* (introduced by J. W. Straley).—A new class of solutions has been discovered to Einstein's field equations for empty space. Among these are some which appear to represent spherical gravitational waves, whose existence within the theory was previously doubted.

C4. Quantum Mechanical Theory of Plasma Oscillations. P. B. BURT AND E. G. HARRIS, *The University of Tennessee.*—By using a self-consistent field approximation, the problem of small amplitude oscillations in a plasma is considered. In contrast to previous treatments the many particles density matrix is used. This formulation has the advantage that proper account can be taken of the statistics obeyed by the particles of the plasma. It is found that the statistics enter only in the form of the unperturbed distribution function.

C5. Bound States in a Hard Core Potential. A. P. FRENCH, *University of South Carolina.*—Some preliminary calculations have been made on the energy levels for a particle in a spherical well with an infinitely hard core. The behavior of the levels with $l=0$, 1, 2 has been studied as a function of (a) the depth of the potential and (b) the ratio of the radius of the core to the radius of the well. As applied to a system of nuclear dimensions, this work to some extent complements studies made by M. A. Preston and co-workers[1] on the scattering properties of potentials with repulsive cores.

[1] M. A. Preston *et al.*, Can. J. Phys. **33**, 309 (1955) and subsequent papers.

C6. Events in Quantum Theory. INGRAM BLOCH, *Vanderbilt University.*—The divergence of the Lagrangian formulation and the lack of a precise definition of x, y, z, t in quantum field theory suggest a new attempt at an "action-at-a-distance" theory in which events rather than systems are primary. Events are described by vectors in a Hilbert space. Space-time coordinates are defined by events whose vectors are coordinate eigenvectors. It seems likely that the coordinate eigenvectors are not all orthogonal and possible that space-time has small-scale curvature which may be a quantum effect.

C7. Proton-Proton Scattering.* M. RAZAVY AND J. S. LEVINGER, *Louisiana State University.*—Gammel and Thaler[1] and others have fit observed proton-proton phase shifts by a static potential that includes an infinite repulsive core. We have attempted to fit these phase shifts by a nonsingular velocity-dependent potential of the form $V(r)+\beta p\cdot V(r)p$. (Here p is the operator in grad.) This potential satisfies all requirements for conservation and invariance properties.[2] One can solve Schrodinger's equation exactly (neglecting the Coulomb force) for a velocity-dependent square well: $V(r)=-V_0$, $r<b$, and $V(r)=0$, $r>b$. As shown in the table, we can fit Gammel-Thaler's S phase shifts well for proton energies from 20 to 340 Mev when we choose $V_0=22$ Mev, $b=2.1$ f, and $\beta MV_0=-0.196$. These values fit low-energy scattering with the effective range parameters $r_0=2.6$ f and $s=0.95$. We are investigating D phase shifts for this potential and also phase shifts for $V(r)$ of Yukawa shape.

	20 Mev	100	180	260	340
Gammel-Thaler	0.859 rad.	0.379	0.120	−0.069	...
Vel-dep. square	0.903	0.346	0.051	−0.108	−0.168

* Supported by the National Science Foundation.
[1] J. Gammel and R. M. Thaler, Phys. Rev. **107**, 291 (1957).
[2] M. Moshinsky, Phys. Rev. **106**, 117 (1957).

C8. Cross Sections for the $Mg^{24}(n,p)Na^{24}$, $V^{51}(n,\alpha)Sc^{48}$, and $Co^{59}(n,\alpha)Mn^{56}$ Reactions for Neutron Energies between 12.6 and 17 Mev.* F. GABBARD, R. M. HUFFAKER, AND B. D. KERN, *University of Kentucky.*—The excitation functions for the $Mg^{24}(n,p)Na^{24}$, $Co^{59}(n,\alpha)Mn^{56}$, and $V^{51}(n,\alpha)Sc^{48}$ reactions have been measured between neutron energies of 12.6 and

17 Mev. The activation technique was used for determination of the cross sections. Activity from the residual nuclei was observed by counting gamma rays. Absolute values of cross sections for Mg^{24} and V^{51} were obtained by comparison with $Al^{27}(n,\alpha)$, and the $Co^{59}(n,\alpha)$ cross section was measured relative to that for $Fe^{56}(n,p)Mn^{56}$. Cross sections assumed for $Al^{27}(n,\alpha)$ and $Fe^{56}(n,p)$ were 125 and 127 mb, respectively, at 14.3 Mev. The (n,p) cross section for Mg^{24} decreases from 210 mb at 12.75 Mev to 137 mb at 16.6 Mev. The $V^{51}(n,\alpha)$ cross section increases from 65 mb to 85 mb between 13.15 and 16.52 Mev. The cross section for the $Co^{59}(n,\alpha)Mn^{56}$ reaction increases from 32 mb at 12.6 Mev to a maximum of 36 mb near 13.8 Mev and decreases to 25 mb at 16.5 Mev.

* This work was partially supported by the U. S. Atomic Energy Commission.

C9. Neutron Scattering from Lead. J. L. FOWLER, *Oak Ridge National Laboratory.*—Measurements on effectively a 72% Pb^{208}, 26% Pb^{207}, and 2% Pb^{204} sample have been made by subtracting out the effect of Pb^{206} from normal lead by use of an 88% Pb^{206} sample. The total neutron cross section of this sample, as well as that of normal lead, has been obtained from 1 to 4.1 Mev with ~25-kev resolution. A resonance, almost certainly due to Pb^{208}, of about 100-kev width shows up at 1.75 Mev. Its height corresponds to a $J=\frac{3}{2}$ level. The differential cross sections were measured at an energy (1.2 Mev) at which the total cross section is flat, and at energies (2.2 and 3.2 Mev) where the total cross section is rising to a broad maximum centered around 4 Mev. $T(p,n)$ neutrons were scattered by cylinders of lead and detected as a function of angle with a shielded propane counter. Since Pb^{208} is a doubly closed shell nucleus, it is expected that a phase shift analysis of the data together with a knowledge of the bound states in Pb^{209} will allow a phenomenological potential to be defined which describes these bound and virtual states with large reduced widths.[1]

[1] E. G. Corman and J. L. Fowler, Bull. Am. Phys. Soc. Ser. II, **5**, 34 (1960).

C10. High-Resolution Neutron Spectroscopy up to 750 kev.* C. D. BOWMAN, E. G. BILPUCH, R. H. TABONY, AND H. W. NEWSON, *Duke University.*—During the past few years high-resolution total neutron cross sections have been measured at Duke University using neutrons from the $Li^7(p,n)Be^7$ reaction at an angle of 160 deg with respect to the proton beam. The second group of neutrons from the reaction sets an upper energy limit at about 200 kev. To explore the higher energy region, our collimator has been rotated[1] through 180° and operated at a neutron angle of 20 deg. At this angle an energy range from 80 to 650 kev and above can be investigated. Measurements of several elements indicate that the neutron resolution in the overlap region of the two experimental arrangements is comparable at about 150 kev where the resolution is about 800 to 1000 ev. The resolution at the 20-deg position improves with increasing neutron energy and reaches 400 to 600 ev at 600 kev. The total neutron cross sections of K, Sr, Ca, Pb, and Pb^{206} have been measured from 10 to 350 kev using both experimental arrangements. With the 20-deg arrangement Ca, Sr, and Ba (already known from 10 to 200 kev) have been measured from 500 to about 700 kev. The total cross section curves[2] in the higher energy ranges show a large number of narrow peaks superimposed on wider *s*- and *p*-wave resonances. $J\pi$ assignments and other parameters will be presented.

* Supported by the U. S. Atomic Energy Commission.
[1] A gunmount loaned by the U. S. Navy was used for this purpose.
[2] Processed on the Duke University IBM 650 computer under support of the National Science Foundation.

C11. Cross Section for the $Br^{79}(n,2n)Br^{78}$ Reaction. W. L. ALFORD AND D. R. KOEHLER, *Research Laboratory, Ordnance Missile Laboratories Division, Army Rocket and Guided Missile Agency, Redstone Arsenal.*—The relative cross section for $Br^{79}(n,2n)Br^{78}$ has been measured for neutron energies from 12.2 to 18.1 Mev. The yields of Br^{78} were determined by measuring the beta activity of 6.4-min half-life. Based on the previously measured value of 788±63 mb at 14.4 Mev,[1] the cross section is found to be 306 mb at 12.2 Mev and 575 mb at 13.3 Mev. From 14.5 to 18.1 Mev the cross section is very constant.

[1] L. A. Rayburn, Bull. Am. Phys. Soc. Ser. II, **4**, 288 (1959).

C12. Radioactivity Induced by Neutron Bombardment of Cd. ARTHUR W. WALTNER, *North Carolina State College.*—The gamma-ray activity of neutron irradiated cadmium is examined through scintillation spectroscopy and decay curve analysis. Neutrons produced by a 1-Mev Van de Graff accelerator using the *D-D* reaction and by the Raleigh Reactor are used in preparing the sources. Scintillation spectra and decay curves for various neutron spectra are presented. A comparison is made between activities resulting from radiative capture and those due to inelastic scattering at different neutron energies. Results are compared with those of Francis *et al.*[1]

[1] A. E. Francis, J. J. G. McCue, and C. Goodman, Phys. Rev. **89**, 1232 (1953).

C13. Thresholds for (p,n) Reactions. C. H. JOHNSON AND A. GALONSKY,* *Oak Ridge National Laboratory.*—Protons accelerated by the ORNL 5.5-Mev Van de Graaff were used to measure thresholds for (p,n) reactions in intermediate-weight nuclei. Targets of separated isotopes were electroplated or evaporated (excepting Nb^{93}) onto platinum blanks; the Nb target was a solid foil. Neutrons were detected by a 4π counter. The target nuclei and their corresponding thresholds in kev are as follows: Fe^{57}, 1648±3; Ni^{61}, 3074±4; Zn^{68}, 3763±5; Ga^{69}, 3050±4; Ge^{74}, 3393±5; Se^{80}, 2684±4; Pd^{106}, 3785±10; Pd^{108}, 2700±100; and Cd^{112}, 3430±15. Each threshold except that for Fe^{57} is consistent with energy differences obtained[1] from positron decay or other threshold measurements. The Fe^{57} threshold corresponds to a Co^{57}-Fe^{57} ground-state energy difference of 837±3 kev rather than 570±30 kev as given in the nuclear data sheets.[1] Thresholds were also observed on the Y^{89} target at 4254±7 kev and on the Nb^{93} target at 2750±100 kev. Each of these is interpreted as a threshold to a known[1] excited state in the product nucleus; in each case the ground state transition is inhibited by a large spin change.

* Now at MURA, Madison, Wisconsin.
[1] Anderson, Fuller, Marion, Way, and Yamada, *Nuclear Data Sheets* edited by C. L. McGinnis (National Academy of Sciences—National Research Council, Washington, D. C., 1958–59).

High-Energy Nuclear Physics

Invited Papers

D1. K^- Meson Interactions in Hydrogen and Deuterium. GEORGE SNOW, *University of Maryland.*
D2. Photo-Pion Reactions and Photodissociation. C. E. ROOS, *Vanderbilt University.*
D3. Low-Lying Energy Levels in the Proton. V. P. KENNEY, *University of Kentucky.*

Contributed Papers

D4. Emission of Neutral Pions.* D. T. KING AND R. L. CHILDERS, *The University of Tennessee.*—The creation of neutral pions in pion-nucleus collisions has been studied in 600-μ Ilford K5 emulsions exposed in the 3.5 Bev/c negative pion beam at the Bevatron. The angular distribution of neutral pions produced in these collisions is deduced from the observed angular distribution of highly collimated electron pairs found in the emulsion. These electron pairs are due to the conversion of energetic gamma rays which arise from the decay of neutral pions. Under the assumption that pion creation occurs only in single pion-nucleon encounters, we infer the π° angular distribution in the pion-nucleon C system. This may be compared with charged pion emission from pion-nucleon collisions[1] and also with the corresponding π° angular distribution in 7.2 Bev/c proton-nucleon interactions derived from measurements on proton-nucleus collisions in emulsion.[2] The C-system available energy is nearly the same in these interactions.

* Supported by the National Science Foundation.
[1] W. D. Walker, Phys. Rev. **108**, 872 (1957).
[2] D. T. King, Phys. Rev. **109**, 1344 (1958).

D5. Comparison of Double and Triple Pion Creation at 2.7 Bev.* W. M. BUGG AND D. T. KING, *The University of Tennessee.*—Among 105 "hydrogen" stars that satisfy all the criteria for proton-proton collisions, we distinguish seven examples of triple pion emission and eleven of double pion emission. These observations have been made in 400-μ Ilford G5 emulsions exposed to the 2.7-Bev proton beam of the Cosmotron, and we have found a multiplicity distribution in reasonable agreement with foregoing work.[1] The C-system kinetic energy distribution of pions from double production interactions is peaked more narrowly and at a lower energy than might be expected from an excited nucleon-isobar model.[2] The C-system pion kinetic energy for triple production stars is peaked at a still lower energy but exhibits a pronounced tail toward higher energies.

* Supported by the National Science Foundation.
[1] R. Cester, T. F. Hoang, and A. Kernan, Phys. Rev. **103**, 1443 (1956).
[2] S. J. Lindenbaum and R. M. Sternheimer, Phys. Rev. **105**, 1874 (1957).

D6. Nuclear Disintegrations Produced by 3.5-Bev Pions.* R. L. CHILDERS, W. M. BUGG, AND D. T. KING, *The University of Tennessee.*—A stack of 600-μ, Ilford K5 emulsions has been exposed in the 3.5-Bev/c negative pion beam at the Bevatron. Nuclear stars have been found by following approximately 100 m of beam tracks. If we assume a geometrical cross section for pion-nucleus interaction, it is possible to estimate the muon and electron contamination of the beam. The momentum distribution of the beam particles which cause nuclear disintegrations has been determined by multiple scattering measurements. The angular distribution of the emergent shower particles and other appropriate characteristics of these stars will be presented.

* Supported by the National Science Foundation.

D7. Lifetime of the Λ^0 Hyperon.* C. C. CHANG, R. GESSAROLI,† AND C. MELTZER, *Duke University.*—The Duke University Helium Bubble Chamber, 20×12×10 cm³, was exposed to a separated low momentum K^- beam at the Berkeley Bevatron. The chamber was operated in a magnetic field of 14.3 kg. A total of 200 decaying Λ° particles with a mean momentum of ~250 Mev/c, produced by K^- absorption in the Bubble Chamber, has been analyzed to obtain an experimental value for the Λ° lifetime. Stereo reconstruction and momentum analysis of these events were carried out by an IBM 650 computer. The Λ° momenta were determined by analysis of the Λ° decays, using kinematically optimized values of the measured angles, momenta, and ranges of the decay products. These data, along with the potential and observed path lengths of the Λ°'s in the chamber, are used to construct a maximum likelihood estimate of the Λ° lifetime. Results will be presented.

* This work was supported by the Office of Naval Research.
† On leave of absence from Bologna University, Bologna, Italy.

D8. Interaction of Cosmic-Ray Neutrons with the Earth's Surface. R. D. EDGE, *University of South Carolina.*—The distribution of cosmic-ray neutrons at a water-air interface has been computed and measured previously.[1] However, the air-earth interface shows a very different pattern for the neutron flux. The composition of the earth's surface is such that both the production and moderation of cosmic-ray neutrons is largely independent of the environment, the only significant variable being the water content. By using known values for production rates, and the data of Harvey and Hughes for the diffusion of the neutrons, a broad dip or minimum in the flux was computed to occur at an altitude of approximately 1700 ft above the earth's surface for neutrons in the energy range 10 to 105 ev. Beneath the surface a broad maximum or merely a change in the gradient of the flux is expected at a depth of approximately 70 g/cm². For slow neutrons, an abrupt increase should occur at and below approximately 300 ft above the earth and a decrease in the flux gradient at around 40 g/cm² below the earth. The effect of moisture content of the air and soil will be discussed. Experiments in progress to measure this effect will be described.

[1] H. A. Bethe, S. A. Korff, and G. Placzek, Phys. Rev. **57**, 573 (1940).

D9. Photodissociation between 1160 and 1350 Mev.* ALFRED D. MCINTURFF AND CHARLES E. ROOS, *Vanderbilt University.*—G-5 nuclear emulsions were exposed to the direct beam of the California Institute of Techuology electron synchrotron. The yields of photostars, or events producing 2 or more charged particles, were measured at 1160, 1290, and 1350 Mev. The highest previous measurement was at 1143 Mev.[1] The photostar yield is an increasing monotomic function of the peak bremsstrahlung energy. The slope of this curve is the cross section/photon (photon difference method). The present data indicate that the excitation curve flattens above 1150 Mev. This means that the cross section/photon decreases with increasing energy. The photostar cross section has been shown to be a measure of the total photo pion cross section. The decrease in photon cross section suggests that the multiple pion cross section passes through a resonance and decreases above 1 Bev. An area 70% larger than the exposed region was scanned. The background corrections were small and the scan efficiencies were more than 90%. The preliminary photostar cross sections/nucleon are: 1160 Mev—352±25 μb; 1290 Mev—401±20 μb; 1350 Mev—386±25 μb.

* This work was supported in part by U. S. Atomic Energy Commission and the Research Corporation.
[1] C. E. Roos and V. Z. Peterson, "Photodissociation of complex nuclei at energies between the mesonic threshold and 1143 Mev" (unpublished).

Microwaves, Solid State, and Cryogenics

Invited Papers

E1. Microwave Properties of Ferrimagnetic Garnet Materials. G. P. RODRIGUE, *Sperry Microwave Electronics Company.*

E2. Microwave Atomic Zeeman Spectrum of Chlorine. H. G. ROBINSON, *Yale University.*

E3. Low-Temperature Studies of Irradiation Effects. T. H. BLEWITT, *Oak Ridge National Laboratory.*

Contributed Papers

E4. Metal Ion Substitutions in Microwave Garnets. GORDON R. HARRISON, *Sperry Microwave Electronics Company.*—Magnetic and crystallographic properties of garnet materials have been studied by many investigators.[1] Only a few of the compositions derived have properties suitable for microwave applications. Yttrium-iron garnet ($3Y_2O_3 \cdot 5Fe_2O_3$), the most useful of these, has been used in this work as the basic composition to study the microwave properties of various metal ion substitutions. Partial substitutions of gadolinium and samarium have been made in the structure for yttrium; partial substitutions of aluminium, gallium, and chromium have been made for iron. The crystallographic location of these ions in the garnet structure largely control the microwave properties of the material. The magnetizations, line widths, g factors, and curie temperatures have been measured for the substitutions mentioned and will be discussed in regard to metallic ion location. The variation of these properties with temperature and effects of property control for microwave applications will be analyzed briefly.

[1] F. Bertaut and F. Forrat, Compt. rend. **242**, 382 (1956); R. Pauthenet, Compt. rend. **243**, 1499 (1956); M. A. Gilleo and S. Geller, Phys. Rev. **110**, 73 (1958); G. P. Rodrigue, thesis, Harvard University, 1958.

E5. Production of Pulsed Magnetic Fields for de Haas-van Alphen Measurements.* N. H. ZEBOUNI, T. MEE, AND J. M. REYNOLDS, *Louisiana State University.*—Magnetic fields in the 10^5 gauss range with stringent conditions on the homogeneity have been produced in the following manner. The field is produced by the discharge of a bank of 1600 μf, 4-kv bank of low-inductance, oil-immersed capacitors into a wire-wound coil. Two parallel-current busplates separated by 12 layers of 3-mill polyethylene sheets constitute the closely spaced, low inductance leads. The design of the coil was determined by the very high homogeneity required in de Haas-van Alphen studies and the fact that a half-period of discharge in the millisecond range was desired. The magnetic forces exerted make strong structural support of the coil necessary. A satisfactory technique providing both mechanical support and dielectric insulation was found by the use of epoxy resin both between layers and as a casting around the coil. A return path for the magnetic field was tentatively provided by filling the casting resin with iron powder. A field of 80 kgauss for a peak current of 2000 amp is obtained with a half-period of 8.5 msec. Several photographs with field trace and current trace simultaneously recorded will be shown.

* Supported by the Office of Ordnance Research, U. S. Army.

E6. High-Pressure Apparatus for the Study of Pressure Dependence of Galvano- and Thermomagnetic Effects in Metals.* R. J. DECK, J. M. REYNOLDS, AND C. G. GRENIER, *Louisiana State University.*—A piston and cylinder combination using solid hydrogen as a pressure transmitting medium has been constructed for the purpose of studying pressure dependence of galvano- and thermomagnetic effects in metals. The apparatus is designed to produce a maximum of 5000 atm of pressure in a $\frac{1}{4}$-in. diameter cylinder. At present it has been operated successfully up to 3000 atm. The technique involved is that originally pioneered by Stewart and Swenson[1] for generating high hydrostatic pressure at liquid helium temperatures. The piston and cylinder are made of beryllium copper and are lap-fitted and polished. A seal was effected between the surfaces of the piston and cylinder by means of a potassium ring on the piston which supports the force applied to the piston. Hydrogen was condensed into the cylinder during the process of bringing the apparatus to liquid helium temperatures. Construction and operating details will be discussed.

* Supported by the Office of Ordnance Research, U. S. Army.

[1] J. W. Stewart and C. A. Swenson, Phys. Rev. **94**, 1069 (1954).

E7. Temperature and Field Dependence of Oscillatory Galvanomagnetic Effects in Tin at Liquid Helium Temperatures.* K. S. BALAIN, C. G. GRENIER, AND J. M. REYNOLDS, *Louisiana State University.*—Subsequent to an earlier communication,[1] a detailed study has shown that for galvanomagnetic effects (Hall and magnetoresistance) well-defined oscillations are superimposed on a large monotonic component while the thermomagnetic effects (Ettinghausen-Nernst and thermoelectric power) are pure oscillatory within an accuracy of $\frac{1}{2}$ to 1×10^{-9} v. Measurements made at various temperatures from 1.1°K to 4.2°K and fields from 10 to 18 kgauss show the amplitude of the oscillations in each effect to be strongly dependent on temperature and field. By analyzing the temperature and field-dependent data of magnetoresistance in light of Zil'berman's theory, a Dingle temperature of 2.2°K has been estimated. From the temperature dependence of the oscillatory part of the magnetoresistance, β^*, the effective double Bohr magneton and so the effective mass $m^*(\beta^* = 4h/\pi m^* c)$ of the carriers has been evaluated. With this value of β^* and the period β^*/E_0[1] known, the chemical potential E_0 has been calculated and found to be in fair agreement with Shoenberg's[2] value from magnetic susceptibility studies.

* Supported by the Office of Ordnance Research, U. S. Army.

[1] J. M. Reynolds, K. S. Balain, and C. G. Grenier, Bull. Am. Phys. Soc. Ser. II, **5**, 58 (1960).

[2] D. Shoenberg, Phil. Trans. **A245**, 891 (1952).

E8. Oscillatory Righi-Leduc Effect in Zinc at Helium Temperature.* C. J. BERGERON, C. G. GRENIER, J. M. REYNOLDS, AND N. H. ZEBOUNI, *Louisiana State University.*—Reported here are initial observations of de Haas-van Alphen oscillations in the Righi-Leduc effect in a zinc single crystal at liquid helium temperatures. A heat current of 10^{-3} w was passed down the length of the crystal, with the magnetic field parallel to the hexagonal axis and perpendicular to the heat current. The temperature gradient transverse to the heat current was measured. Data were taken at 2°K and 3.8°K for the two opposite directions of the field. No Umkehreffekt was observed, as the slight asymmetry of the two experimental curves $\Delta T(H)$ and $\Delta T(-H)$ was within the difference in the calibration curves of the two transverse thermometers. The heat current in the crystal was 10^{-3} w. The transverse thermal resistivity λ_{21}^{-1} at 2°K has been computed and its values compared to those of the transverse electrical resistivity ρ^{21}, obtained from

previous Hall-effect measurements on the same crystal at the same temperature. A remarkable concordance is apparent in both the monotonic behavior and the phase of the oscillations with respect to the field values. The apparent Wiedemann-Franz ratio is computed and its behavior is discussed.

* Supported by the Office of Ordnance Research.

Invited Paper

F1. Current Status of the Strange Particles. BERNARD T. FELD, *Massachusetts Institute of Technology.*

Solid State and Plasma Physics

Contributed Papers

H1. Effect of Plastic Deformation on the Optical Absorption Edge in AgCl Crystals.* M. MILLER AND L. SLIFKIN, *University of North Carolina.*—In a study of the effect of low-temperature plastic deformation upon the optical properties of alkali halides, Chiarotti found a shift in the absorption edge toward longer wavelength of about 10 to 12 A per percent plastic strain. This shift may be discussed in terms of the following possible effects: (a) relaxation of selection rules in the vicinity of dislocations; (b) variation of energy gap in the strained regions; (c) production of new electron levels on the defects introduced by the strain. In the present experiment a similar shift was sought in silver chloride crystals. Measurements were made both at room temperature and at liquid nitrogen temperature (where the edge is sharper and dislocations would not be expected to be able to participate in any annealing process). The absorption edge was measured by means of a Leiss double monochromator, which was capable of showing a shift as small as 1 A. Extensions of 3% were found to produce no measurable effect at either room temperature or liquid nitrogen temperature. The relation of these results to the absorption edge process and its dependence on changes of lattice dimensions will be discussed.

* Supported in part by Office of Ordnance Research, U. S. Army.

H2. Electrical Effects of Plastic Deformation in Silver Chloride Crystals.* H. P. LAYER AND L. SLIFKIN, *University of North Carolina.*—The rapid plastic extension of AgCl crystals gives rise to two transient electrical effects which appear to be independent processes. First, straining produces an enhanced conductivity over and above the increase associated with the presence of stationary dislocations. This transient excess conductivity is about 0.3% ($2.1\times10^{-10}\ \Omega^{-1}\ \mathrm{cm}^{-1}$) for a strain of 1% produced in a time of a few milliseconds and decays after deformation has ceased with a relaxation time of about 2 msec at room temperature. It is believed to be due to the creation of interstitial silver ions by intersecting dislocations. The second effect is a dc pulse developed across the faces of the crystal perpendicular to the direction of elongation. Strains of the magnitude described above may produce potential differences of as much as a few tenths of a volt. This voltage begins to decay before the straining has been completed, and, while it is apparently due to the inhomogeneity of motion of charged dislocations, its kinetics are not understood. Experiments on different crystals all cut from the same original specimen suggest a strong dependence on crystallographic orientation.

* Supported in part by the Office of Ordnance Research, U. S. Army, and the U. S. Atomic Energy Commission.

H3. Diffusion of Silver and Gold Tracers in Crystals of Ag-Au Solid Solutions.* A. GARDNER, R. BASS,† W. MALLARD,‡ AND L. SLIFKIN, *University of North Carolina.*—Since silver and gold form solid solutions over the entire range of composition, studies of self-diffusion in such solutions affords a means of investigating the dependence of diffusion parameters upon crystal properties. The approximately 65 successful measurements performed to date represent about two-thirds of the data required to give a complete picture. Some of the interesting features that have emerged thus far are: (1) At a given temperature the diffusion coefficient of either tracer vs composition of the crystal is not monotonic but appears to go through a minimum near the 50-50 composition. The implications of this fact for further experimentation will be discussed. (2) Although at any composition the diffusion of gold tracer requires a greater activation energy than that for silver tracer, the addition of more gold decreases the activation energies for both tracers. (3) Although silver tracer diffuses faster than gold at any given temperature and composition, it appears that addition of silver to pure gold reduces the diffusion coefficients. (4) Diffusion activation energies decrease with increasing gold content, although the melting point increases. (5) The frequency factor for Au^+ is greater than that for Ag^+, contrary to expectation.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Oak Ridge National Laboratory.
‡ Now at Emory University.

H4. Magnetism of Interacting Donors. I. Theory. H. C. SCHWEINLER AND EDWARD SONDER, *Oak Ridge National Laboratory.*—The magnetic susceptibility attributable to donors in semiconductors (N_d per unit volume) is calculated for the case of a set of pairs of donors, each pair possessing zero, one, or two electrons. It is assumed that the distribution of interdonor distance r of these pairs is the Poisson distributing $dP/dr = \exp(-4\pi N_d r^3/3) N_d 4\pi r^2$, and the resulting expression is averaged over this distribution. The energy of each donor molecule or molecule ion is assumed to be that from experiment for hydrogen (as a function of internuclear distance), appropriately scaled for dielectric constant K and effective mass m^*. The final expression for the paramagnetic susceptibility X is $X = C/T^{1-\alpha}$, where C and α are determined by N_d, K, m^*, and the triplet-singlet energy difference in H_2. These latter quantities are given by experiment, so there are no adjustable parameters in this theory.

H5. Magnetism of Interacting Donors. II. Application to Silicon. EDWARD SONDER AND H. C. SCHWEINLER, *Oak Ridge National Laboratory* (introduced by J. H. Crawford, Jr.).—In silicon the wave functions of electrons frozen out on donor atoms begin to overlap when the density exceeds $10^{17}\ \mathrm{cm}^{-3}$. Measurements of the magnetic susceptibility of a number of samples of silicon, doped with between 5×10^{16} and 5×10^{18} arsenic atoms per cm^3, show that the magnetism of the donors follows a Curie (T^{-1} power) law for the case of the purer samples but deviates from it at low temperatures for the case

of the more heavily doped samples. This deviation is in substantial agreement with the lowered exponent predicted by theory.[1]

[1] H. C. Schweinler and Edward Sonders (preceding abstract).

H6. On the Mechanism for the Production of *F* Centers in NaCl by Irradiation with Gamma Rays. F. W. Young and J. H. Crawford, Jr., *Oak Ridge National Laboratory.*—Seitz[1] has suggested that excitons created during irradiation of ionic crystals recombine at crystalline imperfections such as dislocation jogs. Sufficient energy thereby can be deposited at the jogs to permit evaporation of vacancies from the dislocations, these evaporated vacancies becoming ionized subsequently to form *F* centers. Experiments by Nowick[2] have indicated that the rate of production of *F* centers in NaCl is dependent on dislocation densities in the crystal, thereby apparently substantiating the suggestion of Seitz. However, if vacancies are evaporated from a dislocation, climb of the dislocation results. It can be shown that by gamma irradiation sufficient vacancies can be produced in NaCl which, if the Seitz mechanism is responsible, would cause the dislocations to climb distances which are observable with the optical microscope. By locating the positions of the dislocations in NaCl as etch pits before and after gamma-ray irradiation, and by determining the concentration of *F* centers introduced by irradiation, it has been shown that, if any *F* centers were produced by evaporation of vacancies from the dislocations, they were not a significant fraction of the total number.

[1] F. Seitz, Revs. Modern Phys. **26**, 1 (1954).
[2] A. S. Nowick, Phys. Rev. **111**, 16 (1958).

H7. Radiation and Annealing Studies on Defect-Acceptor States in Ge. J. W. Cleland and J. H. Crawford, Jr., *Oak Ridge National Laboratory.*—Prior investigations[1] of thermal recovery at 100°C of lattice defects induced in *n*-type Ge by Co^{60} gamma-ray exposure indicate that one type of defect-produced energy level disappears preferentially in certain samples. Preferential interstitial migration to dislocations or to clusters was postulated; hence, the extent of such migration should depend on the concentration of dislocations and other imperfections capable of capturing interstitials. During an investigation of this hypothesis, the influence of prior plastic deformation, doping with copper by diffusion, and quenching from elevated temperatures on the energy-level structure and thermal-recovery behavior of the defects introduced by gamma irradiation have been explored. These studies are complicated by the fact that each of these methods of imperfection introduction also introduces acceptor states in the vicinity of the irradiation-induced state whose behavior is being evaluated. The influence of these previously introduced imperfections on the apparent energy-level structure of the point defects introduced by Co^{60} gamma rays and the annealing behavior of these specimens will be discussed.

[1] J. W. Cleland, J. H. Crawford, Jr., and D. K. Holmes, Phys. Rev. **102**, 722 (1956); J. H. Crawford, Jr., and J. W. Cleland, J. Appl. Phys. **30**, 1204 (1959).

H8. On the Occurrence of Fiber Orientation in Thin Iron Films. Roger W. Clapp, Jr., *Research Laboratory, Ordnance Missile Laboratories Division, Army Rocket and Guided Missile Agency, Redstone Arsenal.*—The extent to which helium gas present during the formation of thin evaporated iron films is a factor in the inducement of fiber orientation in the films has been investigated. Iron films, in the thickness range 20 to 250 A, were deposited onto Formvar and baked-out silica substrates at temperatures less than 50°C. The films were sufficiently thin to permit study of the film-substrate combination by means of transmission electron diffraction. The diffraction patterns were examined for density variations with a recording microphotometer. No fiber orientation was observed for films deposited in vacuum (10^{-5} mm) or helium at pressures of 10^{-2} mm or 10^{-1} mm. It is concluded that residual air pressures of 10^{-5} mm or greater are unfavorable for the formation of fiber structure in thin evaporated iron films. If the presence of helium is conducive to fiber formation, the fact is not evident at an air partial pressure of 10^{-5} mm.

H9. Determination of the Debye Temperature of Silver by High-Temperature X-Ray Diffraction.* C. A. Reed and J. E. Miller, *Clemson College.*—The Debye temperature of substances has been measured in the past using film techniques. Because of uncertainties in the measurement of the density of x-ray films, a geiger counter diffractometer was employed and the integrated intensities of the diffraction lines determined by measuring the area under the diffraction curves. Debye temperatures were determined using the reflections from the (420) and (422) planes. The sample was polycrystalline, and the sample temperature was ascertained from the Hume-Rothery[1] equation for the lattice parameter of silver as a function of temperature. Corrections were made for the Lorentz polarization factor. The Debye temperature determined was in general agreement with values found in the literature based on specific heat and elastic constant measurements.

* Supported by the National Science Foundation.
[1] Hume-Rothery, Proc. Roy. Soc. (London) **167**, 23 (1938).

H10. Radiometric Measurement of Electron Temperature in the Vacuum Carbon Arc. W. B. Ard, Jr.,* *Oak Ridge National Laboratory.*—The temperature of the electrons in the vacuum carbon arc has been determined by measuring the noise power radiated by the arc at 7.6 and 11.7 kMc. From the power received and the calculated antenna factor, the electron temperature is found to be about 4 ev in a relatively stable arc. This result is consistent with a determination made from spectroscopic measurements.[1] Details of the radiometer and assumption made about the nature of the arc will be discussed.

* Consultant from the University of Florida.
[1] J. R. McNally, Jr., Oak Ridge National Laboratory (private communication).

H11. Use of Floating Double Probes in Arc Plasma Analysis. Charles Cason and T. A. Barr, Jr., *Redstone Arsenal.*—A simple theory makes it possible to estimate the temperature of electrons in thermal equilibrium in a plasma. High electron density does not appear to place a limit upon this theory. Measurement of the current and applied voltage characteristics of the electrical floating double probes makes it possible to determine the floating potential of a body in the plasma. If the gas is pure and pressure is known, the equilibrium temperature of the plasma may be determined from the probe potential. Measurements in an argon plasma will be discussed as an example to illustrate the technique. The plasma is produced by a gas stabilized plasma jet.

H12. Water to Water Arc. W. Grey Stone, James L. Holeman, and Charles Cason, *Redstone Arsenal.*—An arc is described which flows from a water cathode to a water anode. This arc exists in at least two modes, the more common mode exhibiting voltage sensitivity; the less common mode, which occurs only momentarily, being much less sensitive to voltage fluctuations. A study of the current vs arc length characteristics of this arc seems to place it outside of the realm of the four recognized classes of arcs. Color slides of the arc illustrate the influence of small additions of solute to the water.

H13. Studies of the Electromagnetic Radiation from a Fully Ionized Plasma Device. T. G. Roberts and T. A. Barr, Jr., *Redstone Arsenal.*—The fully ionized plasma device is of the linear pinch type and will be described briefly. Experimental studies of the damage caused by electromagnetic radia-

tion from the plasma have been made. An attempt to image the discharge on the surface of a model by use of an elliptical mirror resulted in destruction of the reflecting surface of the mirror. This damage will be described, and a possible mechanism for the damage will be proposed. Time-resolved spectra of the discharge have been made and will be discussed.

Nuclear Physics

Contributed Papers

J1. Measurement of the Internal Conversion Coefficient of the Intense E2 Transition in Co^{58}.* W. F. Frey, J. H. Hamilton, and S. Hultberg, *Vanderbilt University.*—The total conversion coefficient of the ≃810 kev, E2 transition in Co^{58} was measured in an iron-free, double-focusing spectrometer. The method of Hultberg and Stockendal was used.[1] A 4×18 mm², liquid deposited source (≃250 μg/cm²) of Co^{58} was prepared. The internal and external conversion lines were each measured alternately six times. A 2.2-mg/cm², rectangular (5×21 mm²) uranium converter was used for the external conversion studies. The same source and holder were used in both measurements. Only the converter mounted on an aluminum disk to absorb the beta rays was changed. The preliminary result is $(\alpha_2)_{\text{total}}=(3.4\pm0.2)\times10^{-4}$. The theoretical value as obtained from Rose's tables is $(\alpha_2)_{k+l+m}=3.4\times10^{-4}$. This indicates good agreement. In the internal conversion spectrum the *K*, *L*, and *M* lines were not resolved completely. The presence of an ≃1% transition with nearly identical energy was not observed. A new source for high-resolution studies will be made to separate the *K*, *L*, and *M* lines (to obtain the separate conversion coefficients) and to look for the other weak transition.

* Supported in part by a grant from the National Science Foundation.
[1] S. Hultberg and R. Stockendal, Arkiv Fysik **14**, 565 (1959); S. Hultberg, Arkiv Fysik **15**, 307 (1959).

J2. Gamma-Ray Spectrum from Se^{75}. Charles L. Peacock, Jr., and Max Goodrich, *Louisiana State University.*—The gamma-ray spectrum resulting from K capture in Se^{75} was examined with a conventional single-channel scintillation spectrometer using a NaI crystal. By plotting the square root of the pulse height vs the log of the counting rate, it was possible to use a constant width gaussian curve to fit all the peaks, thereby improving the "peeling off" method of analysis. A previously unreported 173-kev gamma was observed which could be a decay from the 477- or 577-kev level of As^{75}. The relative intensities of the observed gammas were measured.

J3. Decay of $Rh^{102}\rightarrow Ru^{102}$. F. K. McGowan and P. H. Stelson, *Oak Ridge National Laboratory.*—The singles and coincident spectra of the γ rays from the decay of Rh^{102}, which was produced by the (p,n) reaction on ruthenium containing 97.2% Ru^{102}, have been measured with scintillation spectrometers. The energies (in kev) and the relative intensities of the γ rays are: 415±4(3.2), 475±5(100), 630±6(17.4), 695±7(9.5), 745±8(0.7), 765±8(6.9), 1050±10(9.7), 1105±8(4.4), 1110±11(4.1), 1365±10(0.67), 1565±13(0.27), 1795±15(0.06), 2040±14(0.06), and 511(31.6). Spins of the levels in Ru^{102} which are consistent with the directional angular correlations of the γ-ray cascades are: 475(2+), 1105(2+ and 4+, doublet), 1525(3), 1840(0+), 1870(?), 2040(2), 2220(3), and 2270(?). A value of $E2/M1\geq225$ for the 630-kev transition $(2+\rightarrow2+)$ was deduced from the composite correlation of the 630−475-kev cascades. The branching ratio of cascade to crossover from the second 2+ state is 1.5±0.3. Gamma-ray spectra have been measured as a function of time for 250 days, and a change in the relative population of the states is observed. From this we infer the existence of a long-lived isomeric state in Rh^{102}.

J4. Decay of I^{132}. R. L. Robinson, E. Eichler, and N. R. Johnson, *Oak Ridge National Laboratory.*—Gamma radiations emitted in the decay of 2.3-hr I^{132} have been investigated with single-crystal and coincident scintillation spectrometers. The energies and relative intensities of the gamma rays observed are 0.24(1), 0.515(17), 0.64(22), 0.673(78), 0.775(65), 0.953(15), 1.142(3), 1.299(2), 1.392(6), 1.45(1), 1.75(0.1), 1.92(0.7), 1.99(0.6), and 2.40(0.1) Mev. The data are consistent with levels in Xe^{132} at 0.673±0.009, 1.448±0.012, 1.964±0.015, 2.10±0.03, 2.401±0.016, and 2.84±0.02 Mev. There is also some evidence for levels at 2.59 and 2.75 Mev. This decay scheme is similar to that proposed by Finston and Bernstein.[1] From the values obtained for the comparative half-lives of the beta-ray transitions and the ground-state spin of $I^{132}(I_0=4)$,[2] the higher-energy levels of Xe^{132} are each expected to have a spin of 3, 4, or 5. Of these spins the results of gamma-gamma angular correlation measurements and the locations of transitions in the proposed decay scheme are in best agreement with the assignments 4, 3, 4, 3, and 3 or 5 for the 1.448-, 1.964-, 2.10-, 2.401-, and 2.59-Mev levels, respectively.

[1] H. L. Finston and W. Bernstein, Phys. Rev. **96**, 71 (1954).
[2] J. E. Sherwood, S. J. Ovenshine, and G. W. Parker, Bull. Am. Phys. Soc. II, **4**, 386 (1959).

J5. Decay of I^{133}. E. Eichler J. W. Chase,* N. R. Johnson, and G. D. O'Kelley, *Oak Ridge National Laboratory.*—The beta and gamma radiations of 21-hr I^{133} have been studied with single- and multi-crystal scintillation spectrometers. Photopeaks of 0.530, 0.630, 0.700, 0.78, 0.874, 1.05, 1.23, and 1.30 Mev have been resolved from the single NaI(Tl) crystal spectra. Gamma-ray spectra have been observed in coincidence with radiations of 0.53, 0.70, 0.87, 1.05, 1.23, and 1.30 Mev, in which additional weak transitions at 0.42, 0.35, and 0.25 Mev appeared. By using an anthracene crystal spectrometer, the I^{133} beta-ray spectrum was obtained; the Fermi plot revealed a weak group at 1.54 Mev and an intense group at 1.23 Mev. The beta spectra in coincidence with 0.53-, 0.87-, 0.70-, and 1.23-Mev gamma rays gave end points at 1.23, 0.89, 0.51, and 0.50 Mev, respectively. These data support a level scheme for Xe^{133} with excited states at 0.233 (the 2.3-day isomeric level), 0.530, 0.87, 1.05, 1.23, 1.30, 1.39, and 1.58 Mev.

* Summer employee from MIT.

J6. Decay of I^{134}. N. R. Johnson, E. Eichler, G. D. O'Kelley, J. W. Chase,* and J. T. Wasson,* *Oak Ridge National Laboratory.*—The gamma-ray spectrum of 53-min I^{134} has been measured with a 3-in.×3-in. NaI spectrometer, and when analyzed showed prominent photopeaks having energies of 0.14, 0.41, 0.55, 0.61, 0.69, 0.76, 0.848, 0.890, 0.98, 1.07, 1.15, 1.28, 1.34, 1.46, 1.62, 1.79, and 2.03 Mev. There was evidence for several additional weak transitions. The spectrum was experimentally corrected for the effect of coincidence summing. Gamma-gamma coincidence measurements have been made with the peaks at 0.41, 0.61, 0.85, 0.89, 1.07, 1.15, 1.34, 1.46, 1.63, and 1.79 Mev. The end point of the beta-ray spectrum was at 2.41±0.05 Mev, and in coincidence experiment involving one anthracene and two NaI detectors it was shown that this group populates the second excited level of Xe^{134} at 1.74 Mev. Also, the spectrum of gamma rays feeding this same

level was determined in a three-crystal (NaI) coincidence measurement. These results, together with additional beta-gamma coincidence experiments, have led to a decay scheme involving levels in Xe^{134} at 0.85, 1.74, 1.92, 2.27, 2.46, 2.64, 2.89, and 3.14 Mev which are fed by beta rays with energies of 2.41, 2.22, 1.69, 1.50, 1.26, and 1.01 Mev.

* Summer employees from MIT.

J7. *K*-Capture Probability in Ce^{139}.* A. L. STANFORD, JR.,† C. H. BRADEN, AND L. D. WYLY, *Georgia Institute of Technology.*—The probability for K capture in the decay of Ce^{139} has been measured using scintillation spectrometers and coincidence counting techniques. The method is independent of internal conversion coefficients and does not involve detection of conversion electrons, but the method is dependent upon measurements and calculations of the absolute efficiency of a K series x-ray detection system. The probability for K capture was measured to be 0.83 ± 0.04. A lower limit on the transition energy between the Ce ground state and the 166-kev level in La is estimated to be 150 kev, but this calculation is dependent upon an estimate of the capture probability for electrons from the M and higher shells.

* Supported in part by National Science Foundation.
† Now at Sperry Microwave Electronics Company.

J8. Low-Energy X-Ray Absorption Coefficient and Jump Ratio Measurements. J. E. BAXTER, P. MATIN,* AND C. E. ROOS, *Vanderbilt University.*—Recent work on Auger transitions and studies of internal conversion have led to a renewed interest in low-energy x-ray absorption coefficients. A single crystal Bragg spectrometer has been used to obtain monochromatic radiation which is detected with a proportional counter. Absorption measurements have been made on gold, indium, and cadium at a series of x-ray energies between 6 and 36 kev.[1] The L jump ratios of gold were: L_1 1.213 ± 0.006; L_2 1.390 ± 0.007; L_3 2.438 ± 0.013. The K jump ratio of indium was 5.753 ± 0.026 and cadium was 6.126 ± 0.032. Measurements are in progress for lead, tin, platinum, and other metals.

* Presently at Wright-Patterson Air Force Base.
[1] Philip Matin, Master's Thesis, Vanderbilt University.

J9. Total Internal Conversion Coefficients of the E2 Transitions from the Sc^{46} Decay.* S. HULTBERG, W. F. FREY, AND J. H. HAMILTON, *Vanderbilt University.*—The total internal conversion coefficients of the 0.89- and the 1.12-Mev gamma rays which follow the beta decay of Sc^{46} were measured in an iron-free double-focusing spectrometer. The new method of Hultberg and Stockendal was used.[1] A 3- $\times$16-mm^2, liquid deposited source ($\simeq$150 μg/cm^2) of Sc^{46} was prepared. The uranium converter for the external conversion studies and the source holder are described elsewhere.[2] The internal $(K+L+M)$ and the external (K) conversion lines of the two gamma rays were each measured alternately six times (24 total measurements). The preliminary results for the total conversion coefficients are 1.6×10^{-4} and 9.6×10^{-5} with an error of the order of 5% (final calculations are in progress) for the 0.89- and 1.12-Mev transitions, respectively. The 0.89-Mev transition $(2^+\rightarrow0^+)$ is pure E2 and the 1.12 Mev $(4^+\rightarrow2^+)$ is essentially pure E2. The theoretical total E2 conversion coefficients as interpreted from Rose's tables are preliminarily found to be 1.6×10^{-4} and 8.9×10^{-5}. Thus results show good agreement between theory and experiment.

* Supported in part by a grant from the National Science Foundation.
[1] S. Hultberg, Arkiv Fysik 15, 307 (1959).
[2] See abstract J1, this meeting.

J10. Anomalous Internal Conversion Coefficient of the 412-kev Transition in the Decay of Au^{198}.* J. H. HAMILTON, W. F. FREY, AND S. HULTBERG,† *Vanderbilt University.*—In a study of E2 conversion coefficients, the results for the pure E2 transitions in Co^{58} and Sc^{46} have been reported.[1] Good agreement was found with theory for these low-Z elements, as may be expected. As an application to a high-Z element, the internal-external conversion method of Hultberg and Stockendal was applied to the 412-kev transition in the Au^{198} decay. A 2.7- $\times$20.6-mm^2 electroplated source was prepared and used with a 5- $\times$21-mm^2 uranium converter. The conversion line and the photoline were recorded alternately 6 times as before.[1] The preliminary result is $\alpha_2=(2.44\pm0.08)\times10^{-3}$ (theoretical value 23% higher, 3.00×10^{-3}). Our result is in good agreement with that of de Vries.[2] The conclusion is that the latest theoretical E2 conversion coefficients of high-Z unhindered transitions may be in substantial error. Additional E2 transitions are being studied.

* Supported in part by a grant from the National Science Foundation.
† On leave from Nobel Institute of Physics.
[1] See Abstracts J1 and J9, this meeting.
[2] Thesis, University of Amsterdam, Amsterdam, Holland, 1960 (privately published).

Nuclear Physics

Invited Paper

K1. Scattering of Polarized Protons from Light Nuclei. W. HAEBERLI, *University of Wisconsin.*

Contributed Papers

K2. Total Cross Sections of $Ge^{70,72,74,76}$, Cu^{63}, Co^{59}. W. M. GOOD, J. H. GIBBONS, P. D. MILLER, AND J. H. NEILER, *Oak Ridge National Laboratory.*—The ORNL millimicrosecond neutron time-of-flight spectrometer has, as part of its program, the measurement of neutron total cross sections in the kilovolt range of energies. Germanium is the first element for which it has been possible as yet to study a number of isotopes. Over the energy range 3–30 kev the following resonances have been found: Ge^{70}: 4.35, 4.95, 5.55, 6.65, 8.5, 9.8, 10.2, 11.7, 13.2, 18.5, 23.8, 25.7, 28.1; Ge^{72}: 4.52, 4.92, 8.9, 11.1, 19.2; Ge^{74}: 4.95, 19.3; Ge^{76}: 4.95, 14.9, 22.3, 29.3. Although the peak positions are well established, some of the measurements have to be repeated before a really reliable figure can be given for the strength functions. Co^{59} has been thought to have a relatively sharp resonance at 4.2 kev and a broad resonance at about 5 kev. With the best resolution achievable at the time, Co^{59} was re-examined; there was definite evidence that the resonance at about 5 kev is in fact two resonances peaking, respectively, at 4.8 and 5.0 kev. Finally, the measurements on Cu^{63} have been repeated and extended up to 10 kev with the following resonances: 4.35, 4.77, 5.14, 5.71, 7.40, 7.80, 9.00, 9.70.

K3. Apparatus for Simultaneously Measuring (p,p'), (p,d), (p,t), and (p,α) Spectra and for Processing the Data. C. D. GOODMAN AND J. B. BALL, *Oak Ridge National Laboratory.*—It has been found that valuable information about nuclear structure can be deduced from measurements of the Q values and differential cross sections of the prominent peaks in the energy distributions of protons, deuterons, tritons, and alpha particles from proton bombardment of sequences of neigh-

boring isotopes. Inasmuch as large quantities of data must be handled, and some of the cross sections are small so that long counting times are required, it was found necessary to build a system which could identify and record the four energy spectra simultaneously and provide the output in a form which could be read by machine. A system has been constructed at the ORNL 86-in. cyclotron which uses a proportional counter-scintillation counter telescope to identify the particles and measure their energies. A multiplier circuit is used in a gating system arranged to record the four spectra in the four quarters of the memory of a 400-channel pulse-height analyzer. The data are punched automatically onto IBM cards which are read into an IBM 704 with a program which converts the data into energy spectra for each particle as functions of Q, channel energy, and laboratory energy. The data are plotted automatically also.

K4. Nuclear Structure Information from Proton-Induced Reactions at 22 Mev. J. B. BALL AND C. D. GOODMAN, *Oak Ridge National Laboratory.*—The (p,d) and (p,t) spectra obtained with the equipment described in the preceding abstract exhibit a marked gross structure. The strong peaks observed are attributed to the pickup of neutrons from single-particle bound states. Angular distributions of the (p,d) reaction allow the individual states to be identified. A comparison of the energy spectra of (p,d) and (p,t) then allows the determination of the binding energy and pairing energy for the single-particle states. In complicated cases the identification of the levels is facilitated by the examination of spectra from neighboring isotopes. By using this technique, the binding and pairing energies of the $2d_{3/2}$ and $1g_{9/2}$ levels at $A=92$ and the $2p_{3/2}$ and $1f_{5/2}$ levels at $A=59$ have been determined. The $Rh^{103}(p,t)$ reaction has been used to establish the mass of Ru^{101} as 100.9370 ± 0.0003 as well as the binding and pairing energy of the $1g_{7/2}$ level at $A=103$.

K5. Angular Correlation Studies in the $C^{12}(d,p\gamma)C^{13}$ Reaction.* N. R. FLETCHER, D. R. TILLEY, D. GERKE, AND R. M. WILLIAMSON, *Duke University.*—Protons leaving the C^{13} nucleus in the 3.68- and 3.86-Mev excited states have been detected by employing a momentum spectrometer[1] and scintillation counter. The angular distribution of these proton groups for deuteron energies of 2.80, 3.23, and 3.70 Mev confirm the previously reported $l_n=1$ for the 3.68-Mev state and $l_n=2$ for the 3.86-Mev state although in general the experimental forward maxima are narrower than those predicted by Butler. The p, γ angular correlations, both of which correspond to mixed γ-ray transitions have been measured for bombarding energies of 2.8, 3.23, and 3.7 Mev with the proton detector set on the stripping peak. The p_2, γ angular correlations (3.68-Mev state) show increasing anisotropy as the deuteron energy is increased. Also the symmetry axes of the experimental correlations show shifts from the respective neutron axes of 5° to 20° over the above deuteron energy range. The deuteron energies were chosen to avoid compound nucleus formation resonances. Angular correlations at other proton angles and in the azimuthal plane are in progress. The data will be discussed in the light of the distorted wave theory.[2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] O. Meier, Jr., N. R. Fletcher, U. R. Wisseman, and R. M. Williamson, Rev. Sci. Instr. **29**, 1004 (1958).
[2] R. Huby, M. Y. Refai, and G. R. Satchler, Nuclear Phys. **9**, 94 (1958).

K6. Gamma-Gamma Angular Correlation Following the Decay of As^{77}. R. W. LIDE* AND M. L. WIEDENBECK, *The University of Michigan.*—The directional correlation of the 276-kev–246-kev gamma-ray cascade in Se^{77} resulting from the beta decay of As^{77} was measured. The resulting correlation function, after correction for finite resolution, was found to be

$$W(\theta)=1-(0.058\pm0.011)P_2(\cos\theta)-(0.009\pm0.015)P_4(\cos\theta).$$

An attempt was made to obtain spin assignments for the excited states of Se^{77} by comparing the above result with the angular distribution of the 246-kev gamma ray following Coulomb excitation as observed by Temmer and Heydenburg.[1] It was found that a spin sequence of either $\frac{1}{2}$, $\frac{3}{2}$, $\frac{1}{2}$ or a spin sequence of $\frac{1}{2}$, $\frac{3}{2}$, $\frac{3}{2}$ for the ground, 246-level, and 522-kev levels of Se^{77} would be consistent with both sets of data. A spin sequence of $\frac{1}{2}$, $\frac{5}{2}$, $\frac{1}{2}$ would be consistent with the present data but not with the Coulomb-excitation data.

* Now at The University of Tennessee.
[1] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

K7. Beta-Gamma Angular Correlation in the Decay of Eu^{154}.* H. G. DULANEY, L. D. WYLY, AND C. H. BRADEN, *Georgia Institute of Technology.*—Previous work[1,2] on the decay of Eu^{154} has shown a spin change of one for the 1840-kev beta group indicating that the transition is ordinary first forbidden. Preliminary measurements have been made on the beta-gamma angular correlation between the 1840-kev beta group and the 123-kev gamma ray which follows the beta decay. Measurements at a beta energy near 1600 kev yield a negative anisotropy ratio of approximately 0.20. The interpretation of these results in terms of the theory and approximations of Morita and Morita[3] will be discussed.

* Supported in part by a grant from the National Science Foundation.
[1] J. M. Cork, M. K. Brice, R. G. Helmer, and D. E. Sarason, Phys. Rev. **107**, 1621 (1957).
[2] M. Abraham, R. Kedzie, and C. D. Jeffries, Phys. Rev. **108**, 58 (1957).
[3] M. Morita and R. S. Morita, Phys. Rev. **109**, 2048 (1958).

K8. Control of Gamma Radiation in Heavily Shielded Target Rooms. H. E. BANTA AND G. W. LEDDICOTTE, *Oak Ridge National Laboratory.*—Consideration has been given to controlling the gamma backgrounds in a massively shielded target room for a Van de Graaff accelerator. Only limited attention seems to have been given to this problem.[1] Some control of those gamma backgrounds that occur naturally, due principally to K^{40} and Th, is possible by the selection of building materials. A study was made of local building materials including portland cement, locally available sand, and crushed rock. The study showed that the K^{40} activity was generally of the order of eight times the thorium activity and that these activities could be reduced by a factor of twenty by using crushed rock in place of sand in the concrete mix. Consideration also was given to activation due to neutron absorption. It was found that in general about 1% of the incident neutrons go into (n,γ) processes followed by undesirable activities. This level of activity could be reduced by some factor of four by the addition of 5 lb of borax per yard of concrete mix. It was shown by strength tests that this amount of borax does not demonstrably affect the concrete; larger amounts are known to do so.[2]

[1] Charles P. Swann, "Matters pertaining to elimination of background in low energy nuclear physics measurements, with special reference to the Bartol ONR generator," Bartol Research Foundation Tech. Rept. (1959).
[2] R. B. Gallaher and A. S. Kitzes, "Summary report on portland cement concretes for shielding," ORNL-1414.

Astronomy and Spectroscopy

Invited Papers

O1. White Dwarf Atmospheres. R. T. GRENCHIK, *Louisiana State University.*

O2. Shapes and Intensities of Absorption Bands in the Infrared Spectra of Simple Molecules in Solution. NELSON FUSON, *Fisk University.*

Contributed Papers

O3. Spectroscopic Studies at High Temperatures. J. R. McNally, Jr., M. R. Skidmore, P. M. Griffin, and G. K. Werner, *Oak Ridge National Laboratory.*—Spectroscopic studies of magnetically confined arc plasmas have revealed significant "temperature" properties of these systems. At the Oak Ridge National Laboratory the magnetically collimated, high-current carbon arc is one such arc plasma under study. It has been found that the ionic temperature obtained from spectral line broadening exceeds 800 000°K whereas the excitation or electronic temperature determined from spectral line excitations is generally less than 60 000°K. A simple mechanism for permitting the electrons to lag the ions in temperature may be the electron energy dumping mechanism of the 8.0-ev resonance state of C^{3+}.

O4. A "New Look" at Assignments for the Stretching Vibrations of the Methyl Group in Solution Spectra. Nelson Fuson, *Fisk University,* and Marie-Louise Josien, Jean Deschamps, Marie-Therese Forel, and Chantal Garrigou-Lagrange, *University de Bordeaux.*—A study of the spectra of some methyl halides, methyl esters, and methylated aromatic compounds, all of which contai n but a single methyl group and no methylene groups, has shown[1] that a number of the traditional assignments for the methyl stretching vibrations of these compounds require revision. This paper reports revised assignments in the 3000-cm^{-1} region not only for the two methyl group stretching vibration fundamentals but also for the second harmonics of the two methyl group bending vibrations.

[1] J. Deschamps, M-T. Forel, N. Fuson, and M-L. Josien, Bull. soc. chim. France, 88 (1959); N. Fuson, M-L. Josien, Deschamps, C. Garrigon-Lagrange, and M-T Forel, Bull. soc. J. chim. France, 93 (1959).

O5. Polarized Absorption and Fluorescence Spectra of 2, 6-dimethylnaphthalene at 20°K. Adnan Zmerli and Henri Poulet, *Centre national de la Recherche Scientifique, Paris, and Duke University* (introduced by H. Sponer).—Polarized absorption and fluorescence spectra of crystal 2,6-dimethylnaphthalene have been obtained and interpreted. The analysis leads to the location of crystal exciton levels at: 30 740±30 cm^{-1} for polarization along the *a* axis; 30 675 cm^{-1} for polarization along the *b* axis; and 30 472 cm^{-1} for the polarization along the *c* axis. The comparison of the experimental results and the theoretical predictions leads to the assignment of a dipolar moment parallel to the short axis of the naphthalene ring for the first transition *S-S* of the 2,6-dimethylnaphthalene.

O6. Laboratory High-Excitation Relative *gf* Values for Ti I. Ray Hefferlin, Barry Cobb, Donald Hall, and Charles Lehman, *Southern Missionary College.*—It was found that a steady arc could be maintained between pure titanium electrodes 1 cm square by using 15 amp at 28 v, dc. The spectrum of this arc has been studied with a previously developed scanning and recording system. From repeated scans of the spectrum it has been found that the excitation temperature of the arc is 4450±150°K, that all lines of lower state energy 2.0 v or below are self-absorbed the same amount for a given unabsorbed intensity I_0, and that lines terminating on the ground states are self-reversed an additional amount $\Delta \log I = -0.5$. Lines of lower state energy 2.5 v or above were then measured on the same records of the spectrum and calculations of *f* values were made. These laboratory *f* values are compared with *f* values for some of the same lines which had been derived from stellar spectra.

O7. Wind Velocities from Artificial Clouds at Altitudes in the 100- to 200-km Region. Howard D. Edwards and John L. Brown, *Georgia Institute of Technology.*—Wind velocity has been determined in the altitude region between 100 km and 200 km from a triangulation study of the drift of artificial clouds created at these altitudes by chemicals carried aloft in rockets. Speeds up to 127 m/sec have been observed and with bearings ranging from 35°E of N to 335°E of N. High wind shear regions have been found in the vicinity of 101, 105, and 113 km.

O8. Special Distribution from Artificial Clouds at Altitudes in the 100- to 200-km Region. John L. Brown and Howard D. Edwards, *Georgia Institute of Technology.*—Spectral emission in the visual region from chemicals released in the upper atmosphere by high-altitude rockets has been studied by means of photometry through narrow-band interference filters. Indications have been obtained of the excitation of the first negative system of N_2^+ at 4238 A and 4278 A as well as the NO-beta band at 3801 A. Emission strengths were of the same order of magnitude as the resonance radiation.

O9. Application of Analog Computing Techniques to Microphotometry.* K. M. Yoss,† R. T. Grenchik, and J. T. Holdeman, *Louisiana State University.*—Objective prism stellar spectrophotography provides a method for the rapid accumulation of large masses of stellar spectra. The advantage of this technique is lost, however, unless some method for the rapid reduction of these data is available. A partial solution lies in the introduction of analog computing techniques to microphotometry. This has been done at Louisiana State University as well as elsewhere. By using a modified Knorr-Albers Microphotometer, an analog computer with an arbitrary function generator, and a fast recorder, it has been possible to reduce the time necessary to produce a tracing by a factor of ten. The stability of the system is good, and the accuracy is comparable with curve-plotting techniques. The instrument will be used for measurements of CN absorption of the weak CN giants and in an attempt to find a good criteria for determining luminosity.

* Supported by the Research Corporation.
† Now at Mount Holyoke College.

O10. Model Hydrogen Convection Zones for Late-Type Stars. Pierre Demarque, *Louisiana State University.*—Model outer convection zones have been constructed for late-type stars, taking into account the ionization of hydrogen and the first ionization of helium. The combined effects of convective and radiative transports are considered, leading to a departure from pure adiabatic conditions and a superadiabatic temperature gradient. Biermann's theory of the mixing length is used in the analysis. The integrations were performed with the LSU IBM-650 computer and were entirely automatic for a given effective temperature, surface gravity, and composition. Several values of the ratio of mixing length to atmospheric scale height also were used.

O11. Computer Program for Constancy of Flux in a Stellar Atmosphere. R. L. Lesseps and R. T. Grenchik, *Louisiana State University.*—In order to calculate the flux in an atmosphere for late B and early A stars, a program was written in Fortransit for an IBM-650 computor. The variables which may be changed for any atmosphere are: effective temperatures, ratio of helium to hydrogen, and pressure and opacity vs optical depth at 5000 A. The helium was included for calculating White Dwarf stars. The helium contributed to the weight of the atmosphere but not to be the absorption. The only absorption considered was due to atomic hydrogen. This was calculated using the Kramers formula. The flux was computed by means of $F(T)=0.8839B(T+0.397)+0.1161B(T+2.723)-d_1B(t_1)-d_2B(t_2)$ which was obtained by A. Reiz. The flux at each optical depth is calculated at several frequencies which were chosen not to correspond to an absorption

line. The flux was then integrated over frequency to give total flux at each optical depth.

O12. Three-Color Photometry of CY Aquarii. ROBERT H. HARDIE AND CHARLES R. TOLBERT, *Vanderbilt University.*—Approximately 1000 observations were made on the ultrashort period variable star, CY Aquarii, period 88 min, in the UBV system. Those observations were made during a 4-month period with the 24-in. telescope at Dyer Observatory. The amplitudes of the three colors are: $V=0.72$ mag, $B=0.92$ mag, and $U=0.80$ mag. The B-V color index changes by 0.20 mag and the U-B color index changes by 0.14 mag.

O13. Method for the Detection of Faint Early-Type Stars. CARL K. SEYFERT, *A. J. Dyer Observatory, Vanderbilt University.*—With the Dyer Observatory telescope and 24-in. objective prism it has been possible to classify stellar spectra to a limit of about 11.5 mag of 15-min exposures on fast blue-sensitive emulsions. This limit is imposed by the light of the night sky, which produces a background fog on the photographs. Hot, high-luminosity stars (A and B type) may be classified or detected solely through observations of the *H* and *K* lines of Ca II ($\lambda=3933$ and 3969). If spectrum plates are taken behind a filter which transmits only in this region, much longer exposures may be made before the sky background becomes too strong. Liquid and interference filters have been developed for this purpose, and it is found that, with these, exposures of at least 3 hr now may be made. On such, A-type stars can be classified and B-stars detected 1 to 2 mag fainter than had been possible previously.

Biophysics and General Physics

Invited Papers

P1. Biophysical Approaches to the Study of Radiation-Induced Chromosomal Breakage. J. KIRBY-SMITH, *Oak Ridge National Laboratory.*

P2. Direct Action Biological Target Studies with Heavy Ions. D. J. FLUKE, *Duke University.*

Contributed Papers

P3. Molecular Weight Measurements with the Magnetically Suspended Ultracentrifuge.* R. D. BOYLE, P. E. HEXNER, AND J. W. BEAMS, *University of Virginia.*—The magnetically supported vacuum type equilibrium ultracentrifuge previously described[1] has been improved and used for the measurement of the molecular weights of a number of substances. The rotor speed can be measured to at least one part in 10^6, the temperature of one part in 10^4, and the radial density ratio to about one part in 10^3. Molecular weight determinations in the range from about 50 to 10^8 can be carried out with roughly the same order of precision. The substances may be dissolved in any solvent which does not attack the quartz centrifuge cell windows. The maximum temperature is set only by the magnetic properties of the steel rotor so that the usable temperature range is comparatively large. A description will be given of the use of the centrifuge in the equilibrium method for the determination of the molecular weights of a number of different organic compounds dissolved in water and in benzine.

* Supported in part by the National Science Foundation.
[1] J. W. Beams, Proc. Am. Phil. Soc. **101**, 63 (1957).

P4. Ions and Ion-Molecule Reactions Produced by the Bombardment of Gases with Alpha Particles and Electrons. RUSSELL BALDOCK, *Oak Ridge National Laboratory.*—Ions induced in gases by alpha particles have been investigated as a function of the pressure in the reactor chamber of a research mass spectrometer. The relative proportion of various ions thus produced is significantly different from that produced by 75-ev electrons, and no multiply charged ions were observed. At pressures of the order of 0.1 mm of Hg in the chamber, higher mass ions are formed by ion-molecule collision processes, and these will be discussed.

P5. Charge Transfer Reactions Induced by Electrons and Alpha Particles. C. E. MELTON, *Oak Ridge National Laboratory.*—Charge transfer reactions of the type $XY^+ + Z \rightarrow XY + Z^+$ for low energy (0–0.15 ev) gaseous ions and various molecules have been studied in a research mass spectrometer. Some energetically possible reactions have high cross sections as expected, whereas other energetically possible reactions were not detected. The results are discussed in terms of excitation energy, *W* values, and competing chemical reactions.

P6. Crystallite Orientation and Spiral Structure of Cotton. LLOYD B. DELUCA AND ROLLIN S. ORR, *Southern Regional Research Laboratory.**—A method is demonstrated by which both crystallite orientation and spiral angle can be directly determined from the x-ray tracings of the 002 diffraction arcs of combed bundles of cotton fibers. Sisson[1] has shown, qualitatively, that the 002 arcs displayed by fibers with an oriented spiral structure can be explained by assuming two equal crystallite distributions separated by twice an average projected spiral angle. If this distribution of crystallites is assumed to be Gaussian, the experimental arc can be generated theoretically. This analysis is applied to several cottons of widely different orientations, and the calculated parameters are compared with those of the gross arcs.

* One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.
[1] W. A. Sisson, Ind. Eng. Chem. **27**, 51–56 (1935).

P7. Effect of Subthreshold Captures on the Fast Fission Factor. G. ROBERT HOKE, *Mississippi State University.**—The fast fission factor is usually defined[1] as "the number of neutrons slowing down past the fission threshold of uranium-238 per primary fission neutron, that is, per neutron produced by thermal fission." The difficulty with this definition, as pointed out by Spinrad,[2] is that it is not consistent with the techniques customarily used in the measurement or calculation of the resonance escape probability. In particular, the neutron captures at energies between the fission threshold and the resonance energy region are not included in either p or ϵ. This difficulty is obviated by defining ϵ as the number of neutrons making first collision with the moderator per neutron arising arising from thermal fission. Based on this viewpoint a formula for ϵ has been derived. The values of $\epsilon-1$ for cylindrical rods of natural uranium calculated by use of this formula are approximately 20% lower than corresponding

values using the older formula. Most of the difference is due to the subthreshold captures.

* Research Participant at Oak Ridge National Laboratory.
[1] S. Glasstone and M. C. Edlund, *The Elements of Nuclear Reactor Theory* (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1952).
[2] B. I. Spinrad, Nuclear Science and Engineering **1**, 455 (1958).

P8. Measurement of Air-Borne Radioactivity. NEWTON UNDERWOOD, *North Carolina State College*, AND C. J. BRIDGMAN, *Wright-Patterson Air Force Base.*—An electrostatic precipitator operating at 170 cu ft per min, 10 000 v, and 4 M.A. was used to collect the dust from the air samples. Radioactive decay curves exhibit various stages of radioactive equilibrium. Gamma-ray spectra obtained at various times during the decay reveal the changing relative importance of the radon and thoron daughters. This information is useful in evaluating man-made air-borne radioactivity hazards.

P9. An Elementary Description of Pressure Diffusion. HAROLD L. WEISSBERG, *Oak Ridge Gaseous Diffusion Plant.*—Elementary considerations of the rate of momentum transfer among the gas molecules in a binary mixture of nonuniform composition are used to explain the physical significance of the terms which appear in the theoretical equation[1] which describes isothermal mutual diffusion. The purpose is to elucidate the effect of a gradient in the *total* as well as partial pressures. The pressure diffusion term in the equation represents the respective tendencies of lighter and heavier molecules to diffuse toward regions of lower and higher total pressure. This term as derived here corresponds to the situation where each species of molecules in the mixture contributes to the total pressure gradient in proportion to its own *mass* (as contrasted to, say, *number*) density. Hence, it cannot necessarily be associated with a flow in which a viscous shear exists. The method used is a generalization of the elementary treatment of mutual diffusion *without* a total pressure gradient as described by Present.[2]

[1] S. Chapman and T. G. Cowling, *Mathematical Theory of Non-Uniform Gases* (Cambridge University Press, New York, 1952), 2nd ed., p. 244.
[2] R. D. Present, *Kinetic Theory of Gases* (McGraw-Hill Book Company, Inc., New York, 1958), 1st ed., pp. 52–55.

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Baxter, J. E.—J8
Beams, J. W.—P3
Bender, R. S.—A4
Bergeron, C. J.—E8
Biggerstaff, J. A.—A11
Bilpuch, E. G.—C10
Blankenship, J. L.—A1
Blewitt, T. H.—E3
Bloch, I.—C6
Bowman, C. D.—C10
Boyle, R. D.—P3
Braden, C. H.—A13, J7, K7
Bridgman, C. J.—P8
Brown, J. L.—O7, O8
Brown, L. W.—A8
Bugg, W. M.—D5, D6
Burt, P. B.—C4
Cason, C.—H11, H12
Chang, C. C.—D7
Chase, J. W.—J5, J6
Childers, R. L.—D4, D6
Clapp, R. W., Jr.—H8
Cleland, J. W.—H7
Cobb, B.—O6
Crawford, J. H., Jr.—H6, H7, L1
Deck, R. J.—E6
DeLuca, L. B.—P6
Demarque, P. —O10
Deschamps, J.—O4
Dulaney, H. G.—K7
Edge, R. D.—D8
Edwards, H. D.—O7, O8
Eichler, E.—J4, J5, J6
Epling, W. Y.—A12
Feld, B. T.—F1
Fletcher, N. R.—K5
Fluke, D. J.—P2
Forel, M-T.—O4
Fowler, J. L.—C9
French, A. P.—C5
Frey, W. F.—J1, J9
Fuson, N.—O2, O4
Gabbard, F.—C8
Galonsky, A.—C13
Gardner, A.—H3
Garrigou-Lagrange, C.—O4
Gerke, D.—K5
Gessaroli, R.—D7
Gibbons, J. H.—K2
Good, W. M.—K2
Goodman, C. D.—K3, K4
Goodrich, M.—J2
Grenchik, R. T.—O1, O9, O11
Grenier, C. G.—E6, E7, E8
Griffin, P. M.—O3
Gross, A. J.—A12
Haeberli, W.—K1
Hall, D.—O6
Hamilton, J. H.—J1, J9
Hardie, R. H.—O12
Harris, E. G.—C4
Harrison, G. R.—E4
Hefferlin, R.—O6
Hexner, P. E.—P3
Hoke, G. R.—P7
Holdeman, J. T.—O9
Holeman, J. L.—H12
Hood, R. F.—A11
Hoover, R. L.—A8, A9
Hudson, E. D.—A5
Huffaker, R. M.—C8
Hultberg, S.—J1, J9
Johnson, C. H.—C13
Johnson, N. R.—J4, J5, J6
Jones, R. J.—A2
Josien, M-L.—O4
Kendrick, N. S., Jr.—A13
Kenney, V. P.—D3
Kern, B. D.—C8
King, D. T.—D4, D5, D6
King, R. F.—A6
Kirby-Smith, J.—P1
Koehler, D. R.—C11
Layer, H. P.—H2
Leddicotte, G. W.—K8
Lehman, C.—O6
Lesseps, R. L.—O11
Levinger, J. S.—C7
Lide, R. W.—K6
Livingston, R. S.—A2
Lord, R. S.—A5
Mallard, W.—H3
Masket, A.—C2
Matin, P.—J8
McClure, J. S.—A7
McEllistrem, M. T.—A11
McGowan, F. K.—J3
McInturff, A. D.—D9
McNally, J. R., Jr.—O3
Mee, T.—E5
Melton, C. E.—P5
Meltzer, C.—D7
Miller, J. E.—H9
Miller, M.—H1
Miller, P. D.—K2
Morris, L. W.—A10
Mosko, S. W.—A3
Neiler, J. H.—K2
Newson, H. W.—C10
O'Kelley, G. D.—J5, J6
Orr, R. S.—P6
Ovenshine, S. J.—A6
Patronis, E. T., Jr.—A13
Peacock, C. L., Jr.—J2
Poulet, H.—O5
Razavy, M.—C7

Reed, C. A.—H9
Reynolds, J. M.—E5, E6, E7, E8
Rice, W. D.—A10
Roberts, T. G.—H13
Robeson, A.—A7
Robinson, H. G.—E2
Robinson, I.—C3
Robinson, R. L.—J4
Rodrigue, G. P.—E1
Roos, C. E.—D2, D9, J8
Schweinler, H. C.—H4, H5
Seyfert, C. K.—O13
Shearin, P. E.—A9
Shearin, T. C.—A4
Sherwood, J. E.—A6
Skidmore, M. R.—O3
Slifkin, L.—H1, H2, H3
Snow, G.—D1
Sonder, E.—H4, H5
Stanford, A. L., Jr.—J7
Stelson, P. H.—J3
Stone, W. G.—H12
Tabony, R. H.—C10
Tilley, D. R.—K5
Tolbert, C. R.—O12
Underwood, N.—P8
Waltner, A. W.—C12
Wasson, J. T.—J6
Weissberg, H. L.—P9
Werner, G. K.—O3
Wiedenbeck, M. L.—K6
Williamson, R. M.—K5
Worsham, R. E.—A3
Wyly, L. D.—A13, J7, K7
Young, F. W.—H6
Yoss, K. M.—O9
Zebouni, N. H.—E5, E8
Ziegler, N. F.—A3
Zmerli, A.—O5
Zucker, A.—C1

MINUTES OF THE SPRING MEETING OF THE NEW ENGLAND SECTION HELD AT WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MASSACHUSETTS, ON APRIL 9, 1960

THE New England Section of the American Physical Society held its annual Spring Meeting on Saturday, April 9, at Worcester Polytechnic Institute, Worcester, Massachusetts. There was a total registration of 70 persons. Hosts for the meeting were the members of the Department of Physics. Professor Allan E. Parker, Head of the Department, handled the arrangements for this successful and enjoyable meeting. The new reactor facility of the Institute was open for inspection as were the teaching and research facilities in the new physics building.

Four contributed papers and one invited paper were presented at the morning session while the afternoon session consisted of three invited papers. The four invited papers were:

Experimental Determination of the Fermi Surface of Metals. ROBERT W. MORSE, *Brown University.*

Diffraction Theory of Aberration. GEORGE C. KRUEGER, *University of Maine.*

Resonance Electron Capture in Atomic Collisions. EDGAR EVERHART, *University of Connecticut.*

Nuclear Physics with the Worcester Polytechnic Institute 1 Kilowatt Reactor. BERNARD HILDEBRAND, *Worcester Polytechnic Institute.*

PHILIP J. BRAY, *Secretary-Treasurer*
New England Section

Contributed Papers

1. $Li^7(n,n^1)Li^{7*}$ and $Li^7(p,p^1)Li^{7*}$ Scattering below 2 Mev. G. H. HETLEY, B. HILDEBRAND, D. H. TOMPKINS, AND B. A. WOOTEN, *The Worcester Polytechnic Institute.*—Experiments now in progress using the WPI 2-Mev Van de Graaff accelerator are designed to measure differential cross sections for inelastic scattering of nucleons from Li^7 leaving the residual nucleus in its first excited state. The scattered nucleon is detected in coincidence with the 0.478-Mev decay γ ray. Energies of both particles are measured by electronic pulse-height methods. It is planned to compare results with a Lamarsh-Feshbach type calculation and with Bjorklund's optical potential calculation. The instrumentation will be described, and results available at the time of the meeting will be reported.

2. Testing of Ultrahigh Vacuum System Components. I. FARKASS AND E. BARRY, *National Research Corporation.*—A discussion is given of methods used to determine the real leaks and material outgassing of demountable components of ultrahigh vacuum systems. Use of a large metal ultrahigh vacuum system with an end vacuum as low as 2×10^{-10} mm Hg to determine the additional gas load resulting from the components under test is described. Application of these techniques to the leak testing of pressurized chambers for use in satellite vehicles is discussed.

3. On Dislocations Formed by the Collapse of Vacancy Disks.* CHARLES ELBAUM, *Brown University.*—The formation of dislocations by the collapsing vacancy disk mechanism is examined for aluminum, copper, silicon, and germanium. It is shown that this mechanism can be important in the case of metals. In the case of silicon and germanium, dislocation loops produced by the above mechanism during usual crystal growth from the melt will not reach sizes detectable by means of the optical microscope. It is suggested that the above conclusions explain why crystals essentially free of dislocations detectable by means of the optical microscope can be produced by growth from the melt in the case of silicon and germanium. Such crystals are grown under very carefully controlled conditions from materials of very high purity. All major known dislocation producing mechanisms, except collapsing vacancy disks, thus are essentially eliminated, whereas the latter are not capable of producing dislocations of detectable size. It appears that for metals, even when purity and solidification conditions are similar to those of silicon and germanium, the prevention of dislocation growth from collapsed vacancy disks will be more difficult.

* Supported by the Office of Naval Research.

4. Lifetime of the 165-kev Transition in Mn^{52}.* A. HRYNKIEWICZ† AND M. DEUTSCH, *MIT.*—By use of a fast coincidence time analyzer we have established an upper limit for the half-life of the 165-kev transition in Mn^{52} following the positron decay of Fe^{52}: $t_{\frac{1}{2}}\leq0.6\times10^{-9}$ sec. This result contradicts the value $12\pm2n$ sec reported by Juliano *et al.*[1] It also removes their arguments for spin assignments in Mn^{52} since the transition is probably not of pure $E2$ character. Mn^{52m} is probably a $2+$ state.

* This work is supported in part by funds provided by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Air Force Office of Scientific Research.

† On leave from Jagellonian University and Nuclear Institute, Crakow, Poland.

[1] J. O. Juliano, C. W. Kocher, T. D. Nainan, and A. C. G. Mitchell, Phys. Rev. 113, 602 (1959).

MINUTES OF THE TOPICAL CONFERENCE ON NEUTRON DIFFRACTION IN RELATION TO MAGNETISM AND CHEMICAL BONDING HELD AT GATLINBURG, TENNESSEE, APRIL 20–22, 1960

BELOW are printed the abstracts of the contributed papers presented at this conference.

Session II. Iron Group Metals

1. Regarding Theory of Magnetism in 3*d* Metals. J. H. WOOD, *MIT.*—Some recent calculations on the band structure of body-centered iron[1] are reported. The writer believes it highly unlikely that the *d*-band in the transition metals is split into two portions as has been proposed by some. Moreover, it appears that the conventional density of states curves for these metals is qualitatively correct, there being small likelihood of, for example, the 4-p band being occupied. Now these proposals were made essentially to account for the results of Weiss and De Marco who observed anomalously low numbers of *d* electrons in iron and in the transition metals preceding iron in the periodic table. Recent work by Batterman and Chipman indicates, however, that Weiss and De Marco were wrong. The results of Batterman and Chipman and the picture of the *d*-electrons provided by the calculations of Stern[2] and the writer would predict for iron a number of *d*-electrons slightly below that which one would obtain if he thought of the configuration of *d*-electrons as being made up entirely of atomic-like wave functions. It would seem that this state of affairs will persist across the entire transition series.

[1] J. H. Wood, Phys. Rev. **117**, 714 (1960).
[2] Abstract 8, this meeting.

2. Comments on the Spin Correlation Problem. JOHN B. GOODENOUGH, *Lincoln Laboratory,* MIT.*—It is argued that a sharp criterion for Pauli paramagnetism, antiferromagnetism, and ferromagnetism and a consistent interpretation of other band-structure related properties of the transition metals and their alloys follow from four postulates that are related to the electron-correlation problem. (1) Localized (Heitler-London "quasi" particles) and collective 3*d* electrons may be simultaneously present at an atom and the critical atom-atom separation below which 3*d* electrons are collective, above which localized, is $R_c \approx (2.9 \pm 0.1)$ A. (2) Localized 3*d* electrons obey Hund's rule and therefore may introduce a localized atomic moment. (3) If it is possible to propagate nearest-neighbor antiferromagnetic order throughout a lattice, then the subbands formed from nearest-neighbor-overlapping orbitals may be stabilized via superexchange ($R > R_c$) or bonding-band formation ($R < R_c$) provided the orbitals are half-or-less filled. (Intra-atomic and nearest-neighbor interactions are stronger than next-nearest-neighbor interactions.) If the orbitals are more than half-filled, the stable bond is compatible with a spontaneous magnetization of the "extra" electrons. (4) If it is not possible to propagate antiferromagnetic nearest-neighbor order, and $R < R_c$, a conventional "metallic" band is formed which may be spontaneously magnetized provided localized ($R > R_c$) electrons are simultaneously present.

* Operated with support from the U. S. Army, Navy, and Air Force.

3. 3*d* Electron Distributions in Fe_3O_4 from Polarized Neutron Measurements. R. NATHANS, *Lincoln Laboratory, MIT,* AND S. J. PICKART AND H. A. ALPERIN, *Naval Ordnance Laboratory and Brookhaven National Laboratory.*—The determination of the individual magnetic form factors on the tetrahedral and octahedral sites in natural magnetite crystals has shown that there are sizable differences in the unpaired electron distribution of the iron atoms on the two sites. Moreover, there is evidence that the radial extensions of the t_{2g} and e_g groups on these atoms are not identical. Such effects show up in the asymmetrical distribution of the charge density on both sites. A comparison of these above form factors with that previously found in metallic iron[1] shows up other interesting differences. The spatial distribution of the unpaired electrons on the metal is more compact. The radial density functions obtained from inversion of the form factor data suggest that, while the mean radii for the Fe^{3+} and iron metal unpaired electrons are nearly the same, the localization of these electrons about the mean is much more pronounced in the case of the metal. Finally, the weak spinel reflections which normally arise only from the oxygen atoms are found to have a magnetic contribution. This observation could result either from a surplus (or deficiency) of the magnetic electron density in the region between anions and tetrahedral cations or from an assignment of a magnetic moment to the oxygen anion itself.

[1] Nathans, Shull, Shirane, and Andresen, J. Phys. Chem. Solids **10**, 259 (1959).

4. Low-Temperature Magnetic Anisotropy Transition in Chromium.* JULIUS M. HASTINGS, *Brookhaven National Laboratory.*—The antiferromagnetic structure of chromium exhibits a complicated superperiodicity at room temperature which is consistent with an antiferromagnetic antiphase domain structure having the spins parallel to the antiphase boundary wall. An alternative model[2] in which the abrupt boundary wall is replaced by a spiral is equally consistent with the neutron diffraction results. Similar neutron studies were reported by Bykov *et al.*[3] although their model is very different. They also reported a low-temperature transition (158°K) to a nonmagnetic state. In attempting to investigate this transition we have obtained results which are most simply interpreted in terms of an anisotropy transition involving a change of spin direction from being parallel to perpendicular to the antiphase domain wall. This anisotropy transition (110°K) is inconsistent with a simple spiral model.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. M. Corliss, J. M. Hastings, and R. J. Weiss, Phys. Rev. Letters **3**, 211 (1959).
[2] T. A. Kaplan, Phys. Rev. **116**, 888 (1959).
[3] V. N. Bykov, V. S. Golovkin, N. V. Ageev, V. A. Levdik, and S. I. Vinogradov, Soviet Phys.—Doklady **4**, 1070 (1960).

5. Current Work on Chromium at Harwell. G. E. BACON, *AERE, Harwell.*—In order to reveal any influence of small traces of impurity on the magnetic structure of chromium, neutron diffraction measurements have been made on Australian samples extremely free from either gaseous or metallic impurities. For the polycrystals, studied by powder methods, the temperature dependence of the magnetic reflection follows, in the main, a Brillouin curve to a Néel temperature of 39°C, but this is succeeded by a substantial tail out to about 200°C. Moreover, the reflection persists below −150°C. It is suggested that there are two different Néel temperatures dependent on domain size and that only the size range giving 39°C shows the antiphase structure of Weiss, Corliss, and Hastings. The single crystal shows a very well-defined Néel temperature of 39°C with only an extremely weak, but apparently definite, tail. In a study of the low-temperature behavior with high angular resolution the disappearance at −110°C of the reflections [00(27/28), (29/28)] as reported by Bykov *et al.* has been confirmed, but it is directly demonstrated,

either by making the angular resolution worse or by realigning the crystal, that the reflections such as [0(1/28)1] still persist, in accordance with Hastings' interpretation of the change as a rotation of the direction of the magnetic moments through 90°.

6. Current Work on Chromium at ORNL. M. K. WILKINSON, E. O. WOLLAN, AND W. C. KOEHLER, *Oak Ridge National Laboratory.*—Since previous neutron diffraction investigations of chromium have indicated different Néel temperatures for powders[1,2] and single crystals,[2,3] experiments have been performed with high resolution to determine if magnetic-short-range order could have influenced the observations from powders. In examinations of three powdered samples, one showed a Néel temperature of 308°K in agreement with single-crystal determinations, but the others gave values close to 450°K. The two powders with high transition temperatures showed three distinct magnetic reflections near the (100) position which could be explained qualitatively by the antiphase domain model[3] if the unit cell length decreased with decreasing temperatures. One of these powders also showed a transition at about 110°K where a single reflection replaced the group of three and suggested that the moment orientation flipped to a direction perpendicular to the antiphase domain wall. The third sample with the low Néel temperature gave antiferromagnetic reflections consistent with either a simple body-centered-cubic antiferromagnetic structure or an antiphase-domain model with the moment direction never parallel to the domain wall.

[1] C. G. Shull and M. K. Wilkinson, Revs. Modern Phys. **25**, 100 (1953).
[2] L. M. Corliss, J. M. Hastings, and R. J. Weiss, Phys. Rev. Letters **3**, 211 (1959).
[3] V. N. Bykov, V. S. Golovkin, N. V. Ageev, V. A. Levdik, and S. I. Vinogradov, Soviet Phys.—Doklady **4**, 1070 (1960).

7. Antiferromagnetism in Disordered Fe-Ni-Mn Alloys. J. S. KOUVEL AND J. S. KASPER, *General Electric Research Laboratory.*—Disordered face-centered cubic alloys in which the nickel in the composition Ni_3Mn is partially replaced by iron, when cooled to 4.2°K in a magnetic field, exhibit magnetic hysteresis loops that are displaced from their symmetrical positions about the origin. However, when the iron concentration reaches 56 atomic percent, this exchange anisotropy behavior disappears, and the temperature and field dependences of magnetization become those characteristic of a simple antiferromagnetic with a Néel temperature of about 250°K. A magnetic transformation at approximately this temperature is also suggested by electrical resistivity measurements. Neutron diffraction measurements at 77°K give definite evidence for long-range antiferromagnetic ordering in this atomically disordered alloy; at room temperature the antiferromagnetic ordering is absent. The magnetic structure is analogous to that previously reported for the Mn-rich Cu-Mn alloys[1]; the average moment per atom is just over one Bohr magneton. At a still higher concentration of iron (65 atomic percent) there is an increase of the average atomic moment of about 25%, accompanied by an increase in the Néel temperature to above room temperature.

[1] Bacon, Dunmur, Smith, and Street, Proc. Roy. Soc. (London) **A241**, 223 (1957).

8. 3*d* Form Factor in Metallic Iron. FRANK STERN, *U. S. Naval Ordnance Laboratory.*—The expansion of the charge distribution which occurs as one goes from the top to the bottom of the 3*d* band in metallic iron[1,2] causes the atomic scattering factor to decrease by almost half. Averaging over the occupied states in the 3*d* band (7 electrons per atom[1]) leads to a form factor about 5% smaller than the value we find for the corresponding configuration of atomic iron. These results were obtained using wave functions calculated without exchange; for wave functions with exchange the effects would be smaller. Our results show that an accurate calculation of atomic scattering factor in a solid-like iron must use the charge density appropriate to the solid, rather than approximating it by a superposition of atomic charge densities.

[1] F. Stern, Phys. Rev. **116**, 1399 (1959); Bull. Am. Phys. Soc. Ser. II, **5**, 169 (1960).
[2] J. H. Wood, Phys. Rev. **117**, 714 (1960).

9. Magnetic Susceptibility of a Chromium Single Crystal. T. R. MCGUIRE, *U. S. Naval Ordnance Laboratory.*—The magnetic susceptibility of a chromium single crystal was found to be almost constant at approximately $3.25 \pm 0.05 \times 10^{-6}$ emu/g over the temperature range 673°K to 77°K. The sample was in the shape of a cylinder (weight, 0.3058 g); measurements have been made along both a [100] and [111] direction, but no anisotropy effects were observed. At 4.2°K the susceptibility increased to 4.00×10^{-6} for the [111] direction and 3.90×10^{-6} in the [100] direction. This crystal was part of the same specimen used by Corliss, Hastings, and Weiss[1] in their neutron diffraction investigation in which they observed a Néel temperature of 308°K. From neutron diffraction measurements another magnetic anomaly has been reported at 158°K by Bykov[2] and co-workers and also Hastings.[3] The measurements reported here indicate that corresponding changes in the susceptibility are less than 0.05×10^{-6} emu/g.

[1] L. M. Corliss, J. M. Hastings, and R. J. Weiss, Phys. Rev. Letters **3**, 211 (1959).
[2] V. N. Bykov, V. S. Golovkin, N. V. Ageev, V. A. Levdik, and S. I. Vinogradov, Soviet Phys.—Doklady **4**, 1070 (1960).
[3] J. Hastings, Gatlinburg Conference (1960).

10. Magnetic Susceptibility of Vanadium-Chromium Solid Solutions. B. G. CHILDS, W. E. GARDNER, AND J. PENFOLD, *AERE, Harwell.*—The magnetic susceptibilities of solid solutions containing up to 80 atomic percent of chromium in vanadium have been measured at 20°, 77°, and 293°K. The susceptibility of all the alloys investigated was only weakly temperature-dependent. A plot of susceptibility at 20°K against chromium concentration shows a number of maxima and minima, the value falling from 300×10^{-6} emu/g atom for pure vanadium to 159×10^{-6} emu/g atom for pure chromium. An interpretation of the susceptibility behavior can be given in terms of the collective electron model.

11. Measurement of the Electronic Specific Heat Coefficient for bcc Alloys of Transition Elements.* C. T. WEI, C. H. CHENG, AND P. A. BECK, *University of Illinois.*—The electronic specific heat coefficient was measured in the temperature range 1.4 to 4.2°K for fifty bcc solid solution alloys in the following binary systems: Ti-V, V-Cr, V-Fe, Cr-Mn, Cr-Fe, and Fe-Co. The electronic specific heat vs electron concentration curves show three quite well separated regions of high density of states. The first of these occurs in alloys with atomic magnetic moments near zero. The second one is found in alloys which have increasing magnetic moments with increasing electron concentration, up to Fe+35% Co along the Pauling-Slater curve. The third region of high density of states extends from Fe+35% Co to the limit of the bcc solid solutions at Fe+75% Co, a range where the magnetic moment decreases with increasing electron concentration.

* Supported by the U. S. Air Force, Wright Air Development Center.

Session III. Magnetic Compounds and Alloys

12. A Neutron Diffraction Study of the Magnetic Phase Transitions in FeS. ARNE F. ANDRESEN, *Institutt for Atomenergi, Kjeller, Norway.*—The room-temperature neutron diffraction diagram of stoichiometric FeS can be indexed on the supercell derived by Hägg and Sucksdorff. The atomic positions given by Bertaut are confirmed, however, with a larger

displacement $\epsilon = 0.050 \pm 0.005$ of the iron atoms than given by him, $\epsilon = 0.035$. The magnetic moments point along the c axis and are ferromagnetically aligned within each c plane and antiferromagnetically aligned in neighboring planes. At the α transition, $T_\alpha \approx 140°C$, the superstructure reflections disappear, and the magnetic moments turn to point perpendicular to the c axis. This gives rise to a strong (0001) reflection, and by studying this as a function of temperature both the α and β transition can be studied in detail. The α transition is found to be rather broad, extending over about 60°C but varying in width and position from sample to sample. This is attributed to a slight oxidation of the sample during the preparation.

13. The α' Transition in the $Fe_{1-\delta}S$ System.* JOSEPH T. SPARKS, WARREN MEAD, AND ALBERT J. KIRSCHBAUM, *Lawrence Radiation Laboratory, Livermore,* AND WALTER MARSHALL, *AERE, Harwell.*—Temperature-dependent neutron diffraction measurements have been made on antiferromagnetic $Fe_{1-\delta}S$ compounds with $\delta = 0.002$, 0.004, 0.010, and 0.037. Compounds with $0 \leq \delta \leq 0.038$ exhibit a sharp kink in the susceptibility at the α' transition ($T_{\alpha'}$) which has been attributed to a sudden 90° spin rotation.[1] Neutron diffraction results for $\delta = 0.002$ and 0.004 show that a sudden spin rotation does occur but at about 20°C above $T_{\alpha'}$, indicating that the susceptibility anomaly at $T_{\alpha'}$ cannot be attributed to a spin rotation of the type suggested.[1] Further investigations show that the α' superstructure disappears at $T_{\alpha'}$ and that the susceptibility exhibits an additional anomaly at the spin rotation temperature. Spin rotations at $T_{\alpha'}$, and phase segregation below $T_{\alpha'}$, were observed for $\delta = 0.010$ and 0.037 as suggested by previous $\delta = 0.02$ results.[2]

* Work performed under auspices of the U. S. Atomic Energy Commission.
[1] E. Hirahara and M. Murakami, J. Phys. Chem. Solids **7**, 281 (1958).
[2] J. T. Sparks, W. Mead, A. J. Kirschbaum, and W. Marshall, J. App. Phys. **31**, 356 S (May, 1960).

14. Neutron Diffraction Studies of T- and S-Type Domains in Antiferromagnetic Oxides. W. L. ROTH AND GLEN A. SLACK, *General Electric Research Laboratory.*—The magnetic moments in NiO are antiferromagnetically ordered below the Néel temperature 525°K. There are two kinds of domain walls in the antiferromagnetic state: T(twin), in which there is an alteration in the pattern of magnetic moments, and S(spin-rotation), in which there is rotation of the direction of magnetization. The T and S walls have been investigated by measuring the neutron diffraction and anisotropies in magnetic susceptibility of single crystals. Complex T-wall configurations occur in crystals cleaved from boules grown by flame fusion. Annealing at 1500°C refines the domain configuration, and the distribution of T walls favors orientations consistent with a common magnetic axis. A similar result was obtained from a crystal grown by deposition from the vapor on a MgO crystal. Stressing an annealed crystal along [111] removes T walls, but S walls may still be present. Spin rotation (or S-wall displacement) begins at a critical field $H_c \approx 2400$ oe, and at $H \approx 6000$ oe the spins are aligned perpendicular to the H field. The critical field for spin rotation appears to increase with the oxygen content of the crystal. When the applied field is removed, there is a spontaneous relaxation of the spins.

15. New Antiferromagnetic Compounds Related to the Al_2O_3 Structure. Pyroniobates and Pyrotantalates of Bivalent Transition Metals. E. F. BERTAUT AND F. FORRAT, *Centre d'Etudes Nucleaires, Grenoble,* AND L. M. CORLISS,* *Brookhaven National Laboratory.*—Compounds of general formulas $Nb_2M_4O_9$ and $Ta_2M_4O_9$, where M = Mn, Fe, Co, Ni, and Mg, have been prepared. With the exception of the Ni compounds which are orthorhombic, the pyroniobates and pyrotantalates have a hexagonal structure, closely related to the Al_2O_3 or corundum structure in which a pattern repeats at translations (000)($\frac{1}{3}\frac{2}{3}\frac{2}{3}$) and ($\frac{2}{3}\frac{1}{3}\frac{1}{3}$). The simplest way to depict the structure is to imagine a replacement in the Al_2O_3 structure of the Al(000) sublattice by Nb (or Ta) cations and of the Al($\frac{1}{3}\frac{2}{3}\frac{1}{3}$) and Al($\frac{2}{3}\frac{1}{3}\frac{2}{3}$) sublattices by the M cations. A more detailed discussion of x-ray and neutron diffraction data and of the crystalline and magnetic structures will be given.

* Guest physicist at Centre d'Etudes Nucleaires, Grenoble.

16. Magnetic Structure of $CrVO_4$.* B. C. FRAZER, *Brookhaven National Laboratory.*—Neutron diffraction measurements have shown that $CrVO_4$ is antiferromagnetic below 50°K. This has since been confirmed by susceptibility measurements by Bozorth and Davis.[1] According to their measurements, the effective moment above the transition point is about 4 μ_B, in agreement with the expected "spin only" value of 3.87 μ_B for Cr^{+3}. The crystal structure of $CrVO_4$ is orthorhombic (space group D_{2h}^{17}—Cmcm).[2] The structure is completely ordered, with Cr^{+3} on octahedral and V^{+5} on tetrahedral sites. All of the neutron peaks with magnetic contributions can be indexed on the chemical unit cell. The temperature dependence of the (001) peak is consistent with that expected from the squared Brillouin function with $S = \frac{3}{2}$. The data are in agreement with a model consisting of alternating ferromagnetic Cr^{+3} sheets on the (002) planes. As expected, there is no magnetic contribution from vanadium. It should be possible to determine uniquely the spin orientations, since the configurational symmetry is orthorhombic, but this has been difficult to do accurately with powder data. Tentative angles which yield a good match with the data are as follows: $\phi_a = 24° 06'$, $\phi_b = 74° 20'$, $\phi_c = 72° 10'$. The author would like to thank Drs. Bozorth and Davis for permission to quote their unpublished measurements.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. M. Bozorth and D. D. Davis (private communication).
[2] K. Brandt, Arkiv Kemi, Mineral. Geol. **17A**, 1 (1943).

17. Magnetic Structure of Holmium Iron Garnet at 4.2°K. A. HERPIN, W. C. KOEHLER,* AND P. MERIEL, *C.E.N. de Saclay.*—The neutron diffraction spectrum of HoFe garnet at 4.2°K exhibits reflections forbidden by the nuclear space group. Thus, it turns out that magnetic moments of Ho atoms are no longer parallel and iron sublattices remain strongly antiferromagnetically coupled. The proposed structure is the following: the direction of the moments of iron atoms is parallel to [111]; under the effect of the crystalline field Ho atoms are split into six magnetic sublattices, $A_1A_3A_2B_1B_2B_3$, the magnetic moment of the A_2 sublattice being deduced from that of A_1 by rotation around ternary axis. The magnetic moment of the Ho^{+++} ion is then 8 μ_B. This structure accounts quite well for the observed magnetic intensities and for their variation with a magnetic field parallel to the scattering vector if one assumes this variation to be due to domain effects. It explains, in particular, that the magnetic reflection (222) does not appear and that the intensity of the (200) reflection does not change with magnetic field.

* Oak Ridge National Laboratory.

18. Magnetic Structure of $MnAu_2$ at Room Temperature by Neutron Diffraction. A. HERPIN AND P. MERIEL, *Centre d'Etudes Nucleaires de Saclay.*—The nuclear structure of $MnAu_2$, tetragonal centered, may be considered as a pile-up, normal to the c axis, of Mn sheets, sandwiched between two sheets of gold. The magnetic moments of Mn atoms in the same sheet are parallel and in the plane of the sheet, but the direction of these moments turns by a constant angle φ around the c axis from one sheet to the neighboring one. To each nuclear peak (hkl) are then associated two magnetic reflections $(hkl)^+$ and $(hkl)^-$. This magnetic structure of helix type accounts quite well for the observed Bragg angles and intensities of magnetic reflections with $\varphi = 51°$. In particular one

observes at low angles the $(000)^{\pm}$ reflection associated with the (000) pole. The study of the influence of a magnetic field either parallel to the scattering vector or normal to the scattering plane on the $(002)^{-}$, $(002)^{+}$, $(101)^{-}$, $(101)^{+}$ reflections shows clearly that only the component of field in the plane of the sheets is effective to disturb the magnetic structure. This explains in particular why the (002) nuclear peak is increased by a magnetic component when field is applied normal to the scattering plane. The magnetization vs field curve calculated for a polycrystalline specimen gives fairly good agreement with the experimental curve of Meyer and Taglang.

19. Iron-Platinum Alloys. G. E. BACON, *AERE, Harwell.*—A preliminary study has been made of some ordered alloys close to the composition Pt_3Fe whose magnetic susceptibility was discussed by Crangle at the 1958 Grenoble conference. The powder diffraction pattern shows two sets of magnetic reflections, represented by $(\frac{1}{2}\,0\,0)$ and $(\frac{1}{2}\,\frac{1}{2}\,0)$ which have different dependences on temperature. The former set show a Néel temperature of about 125°K, corresponding to a minimum which is observed in the reciprocal susceptibility, whereas the latter set disappear at 170°K, near the point of departure of $1/\chi$ from a Curie-Weiss law. From observations on single grains in a polycrystalline ingot it is concluded that the two types of antiferromagnetic structure exist concurrently and independently within a single grain and for what is chemically a single phase. Some possible structural models are discussed in the light of plausible magnetic moments for the iron and platinum atoms.

20. Magnetic Ordering in $CrCl_3$ and $FeCl_3$. J. W. CABLE, M. K. WILKINSON, AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—Neutron diffraction investigations were made on powder and single crystal samples of anhydrous $CrCl_3$ and $FeCl_3$ in an attempt to determine the type of magnetic ordering in these hexagonal layer-type crystals. Observations were made at sample temperatures from 298° to 4.2°K, and both compounds were found to be antiferromagnetic below about 16°K. The magnetic structure of $CrCl_3$ consists of ferromagnetically aligned moments within each hexagonal layer of metal ions but with adjacent layers coupled antiferromagnetically. A spin-only moment of 3 μ_B per chromium ion and the moment direction normal to the c axis of the crystal was indicated. For $FeCl_3$ the magnetic reflections were slightly displaced from the positions in the reciprocal lattice corresponding to allowed superlatice reflections for the $CrCl_3$ type of magnetic structure. This indicates an antiferromagnetic coupling between near neighbors along the c axis and an additional modulation of the magnetic scattering amplitudes in the [230] direction. A simple spiral model is in accord with the observed magnetic intensities. In this model the moments lie within (140) planes and are parallel (and antiparallel along the c axis) in each plane but are rotated by $2\pi/15$ deg in successive (140) planes proceeding along the [230] direction.

21. Interatomic Distances and Magnetism in Some Compounds with the Pyrite Structure.* NORMAN ELLIOTT, *Brookhaven National Laboratory.*—Interatomic distances in MnS_2, FeS_2, CoS_2, and NiS_2 have been re-examined. The S−S bond length is found to vary. This variation and the magnetism of these compounds will be discussed in relation to theories of the pyrite structure.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

22. Ordering Effects in Iron-Rich Manganese Ferrite. EARL R. CALLEN, *U. S. Naval Ordnance Laboratory.*—Though magnetite is inverse, manganese ferrite is 80% normal. Mn^{3+} first goes preferentially on the A sites, up to about 0.4 Mn atom/molecule, beyond which concentration a small fraction populates the B sites as Mn^{3+}. Penoyer and Shafer[1] and others find a remarkable minimum in the first anisotropy coefficient $|K_1|$. At this concentration the tetrahedral sites are about half filled with Mn, which suggested the possibility of A-site ordering. Investigation by Alperin and Pickart indeed showed this ordering, as described in the following abstract. Measurement by T. R. McGuire shows the moment of this sample to be 4.37 μ_B, corresponding to a distribution $Mn_{0.5}^{2+}Fe_{0.5}^{3+}[Mn_{0.1}^{3+}Fe_{0.5}^{2+}Fe_{1.4}^{3+}]O_4$. In the ordered crystal each A ion is surrounded by a regular tetrahedron of A ions of the other kind, and, further, the ordered A ions produce a fully trigonal field at a B site. It has been observed that Fe^{3+} has an appreciable magnetic anisotropy both on A and B sites. We believe the restoration of the symmetry of the crystal field by the ordering is responsible for the minimum in $|K_1|$. Above 1 Mn atom/molecule the moment data imply some complication. We present high-field and high-temperature susceptibility evidence for an angled arrangement.

[1] R. F. Penoyer and M. W. Shafer, J. Appl. Phys. **30**, 315S (April, 1959).

23. Evidence for Tetrahedral Site Ordering in $Mn_{0.6}Fe_{2.4}O_4$.* H. A. ALPERIN AND S. J. PICKART, *U. S. Naval Ordnance Laboratory and Brookhaven National Laboratory.*—Neutron diffraction powder patterns taken at room temperature and 4.2°K yield the following values for the magnetic and nuclear parameters: the cation distribution is $Mn_{0.54}Fe_{0.46}[Mn_{0.06}Fe_{1.94}]O_4$, oxygen parameter $=0.3827\pm0.0005$, unit cell edge $=8.471\pm0.002$ A (from an x-ray pattern), A-site moment $=4.8\pm0.4$ μ_B, B-site moment $=4.0\pm0.4$ μ_B. A single crystal of the same composition showed a 200 reflection (the half-wavelength contamination from the 400 reflection was eliminated with a plutonium filter) indicating a 1:1 ordering on the A sites. A quantitative measurement of the order parameter S (defined by intensity $\propto S^2$) was obtained by measuring the 200 reflection at room temperature on a powder sample. The half-wavelength contamination was measured independently and used to correct the data. The result is $S=0.29\pm0.03$. A measurement of the 200 reflection at 4.2°K (on the same sample but with poorer statistics) indicates qualitative agreement with the result of the room-temperature measurement. We are greatly indebted to Dr. Calhoun of IBM for providing the powder and single crystal samples.

* Performed under the auspices of the U. S. Atomic Energy Commission.

24. Neutron Diffraction Study of $Zn_xMn_{1-x}Fe_2O_4$. JEROME WOYCI AND VICTOR HICKS, *Allen-Bradley Company,* AND S. S. SIDHU, *Argonne National Laboratory.*—Neutron diffraction studies were made of $Zn_xMn_{1-x}Fe_2O_4$, where $x=0.1$, 0.3, and 0.5. Neutron powder patterns were obtained at room temperature and above the Néel temperature. The ratios of the intensities of six (hkl) sets of diffraction peaks were used to determine the ionic distribution. Agreement of observed and calculated intensity ratios of these six sets was achieved by a computer program which allowed independent variation of ξ, the fraction of the Mn^{++} ions on the A sites, and $2B$, the Debye-Waller factor for given values of u, the oxygen parameter. These calculations led to curves of u vs ξ, in sets determined by $2B$, for each of six intensity ratios. The values of u and ξ were read from the set on which the six curves intersected in a point. Thus u, ξ, and $2B$ were determined uniquely. The zinc ions remained on A sites in these compositions. Calculated saturation magnetizations are in agreement with magnetic measurements.

25. Neutron Diffraction Study of Liquid Oxygen. D. G. HENSHAW, *Chalk River Laboratories.*—The angular distribution of 1.04 A neutrons scattered by specimens of liquid oxygen at 90.7°K, 69.0°K, 62.4°K, and 54.7°K has been measured over the angular range 3° to 78°. The low angle scattering is in excess of corresponding x-ray measurements. A comparison of the form of this excess scattering with that

calculated[1] for uncoupled magnetic moments suggests the possible existence of short-range magnetic order in the liquid similar to that observed in solid MnO at room temperature.[2] The measured angular distributions corrected for magnetic scattering were transformed to the radial distribution functions $4\pi r^2[\rho(r)-\rho_0]$. From these, the number of neighbors in and spacing of the diatomic shell are 1.2 atoms and 1.26 A, respectively. The nearest distance of approach of 2 atoms in adjacent molecules in the liquid is 2.7 A, and the spacing of the main density maximum in the liquid is about 3.9 A. The total number of atoms in the main density maximum increases from about 16 to 21 atoms for temperature change from 90.7°K to 54.7°K. The possible existence of the O_4 molecule in the liquid will be discussed.

[1] W. Kleiner, Phys. Rev. **97**, 411 (1955).
[2] C. G. Shull, W. A. Strauser, and E. O. Wollan, Phys. Rev. **83**, 333 (1951).

Session IV. Magnetism in Rare Earths and Other Topics

26. Magnetic and Electrical Properties of Rare-Earth Single Crystals.* S. LEGVOLD, *Iowa State University.*—By using single crystals grown by the Bridgman and strain anneal techniques, the magnetic and electrical properties of a number of the *hcp* rare earth metals have been determined. In magnetic work at low temperatures, values of gJ appropriate to the tripositive ion have been found along the easy a_0 direction for Dy(10.2 vs 10 theoret), and along the easy a_0 direction for Ho(10+exp vs 10 theoret). In the case of Er an experimental value of 8 is found for gJ along the easy c_0 direction compared with a theoretical 9. It is believed that work at high fields along a_0 will yield the theoretical value. In earlier work on polycrystalline Gd and Tb, experimental gJ values close to the theoretical values were obtained (7.1 vs 7 and 10.2 vs 10, respectively). Magnetic anisotropy is large in Dy and Ho. Electrical resistivity measurements on *Y* have shown that, at room temperature, ρ along a_0 is nearly twice as high as ρ along c_0. In the cases of Dy and Er interesting magnetic influences on ρ along c_0 are observed. In particular, sharp increases in ρ along c_0 occur at transitions from ferromagnetic to antiferromagnetic states and peaks in ρ along c_0 occur near the Néel points.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

27. Magnetic Structure Properties of Metallic Holmium. W. C. KOEHLER, J. W. CABLE, E. O. WOLLAN, AND M. K. WILKINSON, *Oak Ridge National Laboratory.*—Magnetic and thermal measurements at Ames on polycrystalline holmium exhibit anomalies at about 132°K and near 20.0°K which are indicative of magnetic ordering transitions. Single-crystal and powder neutron diffraction data have shown the higher temperature anomaly to be a transition from the paramagnetic state to an ordered magnetic structure of the helical type In this structure the screw axis is the *c* axis of the crystal, and the moments are parallel in, and parallel to, the (OOH_3) planes. The interplanar turn angle decreases linearly with decreasing temperature from 48.8° at 119°K to 38.4° at 52°K. For temperatures above about 35°K the map of scattering density in reciprocal space shows only a single pair of satellites disposed symmetrically, along the b_3 axis, about the normal reciprocal lattice points. In particular a very intense pair of magnetic reflections is observed at very small angles corresponding to satellites associated with the (origin (0,0,0). A careful search in the vicinity of the origin revealed no secondary satellites: the sensitivity of the search was such that a secondary satellite 0.01% as intense as the primary one would have been detected.

28. Magnetic Ordering in Rare-Earth Nitrides and Antimonides. M. K. WILKINSON, H. R. CHILD, E. O. WOLLAN, J. W. CABLE, AND W. C. KOEHLER, *Oak Ridge National Laboratory.*—Neutron diffraction investigations have been performed on a group of rare-earth nitrides and antimonides with the rocksalt structure to determine the existence of magnetic ordering in these compounds. HoN, TbN, and ErN become ferromagnetic at about 18°K, 43°K, and 6°K, respectively, and no magnetic ordering was observed in TmN at temperatures down to 1.3°K. On the other hand, HoSb and TbSb become antiferromagnetic at low temperatures with magnetic structures in which the moments are arranged in ferromagnetic sheets normal to the cube diagonal and adjacent sheets are oriented antiparallel. The paramagnetic scattering from all of these compounds agrees satisfactorily with moment values calculated for the free trivalent rare-earth ions, but the moment values in the ordered magnetic structures are lower than the calculated values. Recent calculations by Trammell[1] indicate that these low moment values and the specific orientation of the ordered moments are the result of crystalline field interactions. Diffraction patterns from the ferromagnetic rare-earth nitrides (particularly HoN and ErN) show considerable ferromagnetic short-range-order scattering which has characteristics that are different from those associated with critical magnetic scattering.

[1] G. T. Trammell, J. Appl. Phys. **31**, 362S (May, 1960).

29. Stark Decomposition by Crystal Field in Rare-Earth Oxides, Measured by Neutron Inelastic Scattering. D. CRIBIER AND B. JACROT, *C.E.N. de Saclay.*—The idea of measuring crystal field splitting of rare earth ions by inelastic scattering of slow neutrons ($E_n \sim 4 \cdot 10^{-3}$ ev) has been suggested by A. Herpin. We performed this experiment on the oxides Ho_2O_3 and Er_2O_3 using the Saclay chopper and time-of-flight facilities. We observed the following transitions: Ho_2O_3: 365 cm^{-1} and 76 cm^{-1}; Er_2O_3: 420 cm^{-1}, 81 cm^{-1}, and 40.5 cm^{-1}. Low-energy transitions $\Delta E \lesssim 10$ cm^{-1} are not resolved by our spectrometer and give rise to a broadening of the elastic peak. Calculations on the levels and inelastic cross sections have been carried out in our group by D. Saint-James. A detailed account of these experiments will be printed in *Comptes rendus hebdomadaires des séances l'académie des sciences*, Paris.

30. Magnetic Short-Range Order in Ferromagnets and Antiferromagnets. J. SAMUEL SMART, *Office of Naval Research.*—The experimental evidence on many ferromagnetic and antiferromagnetic systems indicates that both first and second nearest neighbor interactions are important in determining the magnetic properties. However, the theory for such systems is usually limited to one set of interactions only; thus quantitative comparisons of theory and experiment are not possible in general. We have extended the Oguchi method[1] to calculate the magnetic short-range order of a body-centered cubic lattice above the transition point when both first and second neighbor interactions, J_1 and J_2, are present. For convenience, the calculations are restricted to spin $\frac{1}{2}$. The vibration of both short-range-order parameters with J_1 and J_2 and T is discussed, along with the possibility of determining J_1 and J_2 from experiment.

[1] T. Oguchi, Progr. Theoret. Phys. (Kyoto) **13**, 148 (1955).

31. Spin Polarization and the Magnetic Form Factor of Ni^{+++}. R. E. WATSON,* *MIT*, AND A. J. FREEMAN, *Materials Research Laboratory, OMRO.*—Magnetic form factors for tran-

sition metal ions in ionic compounds calculated from free ion charge densities disagree with experiment. Previously, we have reported[1] an investigation of the effect of crystalline fields on the spin density and magnetic form factor for the Mn^{++} ion. This effect appeared to be the principal cause for the large disagreement between experiment and theory. Since the Mn^{++} ion has a half-closed shell with all spins aligned, we have investigated the more general case of a transition metal ion with a nonclosed (but not half-filled) shell for which there are several effects, including that resulting from the crystalline field, which affect the measured magnetic form factor. We here consider the Ni^{++} ion in an ionic crystal (e.g., NiO) with emphasis on the effect of spin (exchange) polarization; the discussion is based on an "unrestricted" Hartree-Fock calculation for the Ni^{++} ion. Spin polarization gives rise to different charge densities for electrons in the same shell but differing in spin, resulting in a net spin density more contracted than the restricted Hartree-Fock free ion *3d* charge density and hence in a larger magnetic form factor than for the free ion. The contribution of the core electrons to the magnetic scattering also will be discussed.

* Now at AVCO, RAD Division, Wilmington, Massachusetts.
[1] A. J. Freeman and R. E. Watson, J. Appl. Phys. **31**, 374S (May, 1960).

32. Neutron Diffraction Form Factor for Mn^{2+}. G. BENEDEK, *Harvard University.*—Measurements[1] of the neutron diffraction form factor in a number of Mn salts indicate that the *3d* orbitals of the Mn ion are spread out radially by 10% relative to the Hartree-Fock solutions for the free ion. A semiquantitative method for calculating this spread-out is proposed. The Mn^{2+} ion is replaced by the spherically symmetrical charge distribution, given by the Fermi-Thomas-Dirac statistical model, whose radius has been calculated[2] as a function of the degree of ionization. In the solid, the orbitals of neighbor ions overlap this sphere. If we regard the neighboring electrons as becoming a part of the Mn charge distribution on entering the FTD sphere, the degree of ionization is reduced by the amount of charge overlap, and as a result the radius of the sphere increases. Calculations have been carried out for MnF_2 where we have considered the effect of the *2p* electrons on the 6 fluorine neighbors. These electrons reduce the ionization of the Mn^{2+} ion from 2 to 1.28, and the resulting change in the ion radius is 15%. Thus the mechanism of charge overlap originally suggested by W. Marshall seems capable of explaining at least semiquantitatively the observed effects.

[1] J. M. Hastings, N. Elliott, and L. M. Corliss, Phys. Rev. **115**, 13 (1959).
[2] L. H. Thomas, J. Chem. Phys. **22**, 1758 (1954).

33. Minimum Energy Spin Configurations in the Spinel Structure. T. A. KAPLAN, K. DWIGHT, AND N. MENYUK, *Lincoln Laboratory,* MIT.*—A recent calculation has shown[1] that the Yafet-Kittel triangular configurations do not minimize the classical Heisenberg energy in the normal, cubic spinel. That is, they are unstable and cannot represent the ground state. We have extended this calculation to include general nearest-neighbor *A-A*, *A-B*, and *B-B* interactions possessing tetragonal symmetry. For any value of the *A-A* interaction, the stable, minimum energy configurations are defined within a space spanned by three interaction parameters. We have found the surfaces in this three-dimensional space which bound the regions of stability for the Néel-Yafet-Kittel configurations for zero *A-A* interaction. Outside these regions, we have investigated the ground state using a perturbation method[1] and a generalization[2] of the Luttinger-Tisza method. We have found the ground state in some regions to be the standard antiferromagnetic spiral. In other regions the ground state is a modified spiral which is ferrimagnetic.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] T. A. Kaplan, Phys. Rev. **116**, 888 (1959); Phys. Rev. (to be published).
[2] D. Lyons and T. A. Kaplan (to be published).

34. Chemical Bond in N_2 and the Superexchange Mechanism.* ROBERT K. NESBET, *Boston University.*—The electronic wave function of N_2 has been calculated for a series of internuclear distances, in the simplest LCAO approximation. As the internuclear distance increases, there is a well-defined sequence of regions in which the ground state is most closely approximated by configurations in which successively more orbitals are represented as localized functions (definitely associated with one of the two atoms) rather than as the odd or even linear combinations of these appropriate to the full molecular symmetry. This corresponds to a continuous change in the nature of the unrestricted Hartree-Fock orbitals from molecular to atomic character as the atoms are separated. In the intermediate range of internuclear separation, it is a better approximation to treat some of the orbitals as modified atomic orbitals, coupled by an antiferromagnetic Heisenberg exchange interaction, rather than as molecular orbitals. Various contributions to the Heisenberg "exchange integral," of the kinds considered for the transition metals, are evaluated and compared.

* This work was supported in part by the National Science Foundation and in part by RIAS, a division of The Martin Company, and was made possible by a grant of use of their IBM 704 computer by The Martin Company at Baltimore.

35. Intramolecular Magnetic Exchange. B. N. FIGGIS, *University College, London.*—The exchange between two paramagnetic ions within the same molecule may serve as a simplified model for considering direct- and super-exchange in the more complicated systems which lead to ferro- and antiferromagnetism. Exchange in systems involving a Cr−OH−Cr bond is much smaller than that in systems involving Cr−O−Cr or Fe−O−Fe bonds. This can be understood if the H atom on the O prevents the O p_z and p_y orbitals entering into π bonding with the metal d_{zz} and d_{yz} orbitals. The magnetic behavior of the $(H_2O$ phenanthroline $Fe)_2O^{4+}$ ion can be described as two t_{2g}^5 systems subject to a ligand field of symmetry lower than cubic and coupled together antiferromagnetically by $J = \sim 250°$. This can be accounted for if the two antibonding electrons in the molecular orbital arrangement from the t_{2g} metal and O p_z and p_y orbitals, $E_u^4 : B_{1g}^2 B_{2}^2 E_g^4 : E^2$ of the D_4h molecule, are taken to weaken the π bonding system so that the molecule bends and a singlet term becomes lowest. By the construction of B_{1g} and B_{2u} MO's between the $d_{x^2-y^2}$ orbitals of the two Cu atoms in D_4h bimolecular cupric acetate, the singlet-triplet transition is explained, while in the similar chromous acetate the $E_u^4 : B_{1g}^2 B_{2u}^2 : E_u$ arrangement explains the diamagnetism.

Session V. Crystal Structure and Chemical Bonding

36. Hydrogen Location Studies by Neutron Diffraction. H. A. LEVY, *Oak Ridge National Laboratory.*—The available data on hydrogen atom location in O−H···O hydrogen bonded systems is reviewed briefly. An inverse correlation between O−H and O···O distances is well established for O···O greater than 2.40 A. For O···O sufficiently short, the hydrogen atom is expected to assume the central position between the oxygen atoms. Several neutron diffraction studies are consistent with centered structures but do not distinguish a second possibility, that of distribution of the hydrogen atom

at random between two symmetric, noncentered sites along the O···O link. Indirect evidence is presented that in two cases the hydrogen atom may in fact be centered: these are the internal hydrogen bond in potassium hydrogen maleate and the short hydrogen bond in acetamide hemi-hydrochloride. The hydrogen atom in an O–H···O link tends to be colinear with O···O, this tendency being greater the shorter the O···O distance, but appreciable departures frequently are found. The mean thermal displacement of the hydrogen atoms in these systems also shows a correlation with the O···O distance, tending to smaller values the shorter the O···O link.

37. Thermal Motion in Palladium Hydride Studied by Means of Elastic and Inelastic Scattering of Neutrons. J. BERGSMA, *Institutt for Atomenergi, Kjeller, Norway,* AND J. A. GOEDKOOP, *Reactor Centrum Nederland, Petten, The Netherlands.*—A single-crystal neutron diffraction investigation of electrolytically loaded palladium hydride of composition $PdH_{0.68}$ confirms the NaCl-type arrangement found previously for material loaded from the gas phase. The root-mean-square displacements caused by thermal motion of the palladium and hydrogen atoms at room temperature are found to be 0.10 ± 0.01 and 0.24 ± 0.02 A, respectively. Measurements of the total neutron scattering cross section as a function of neutron energy and of the energy distribution of 0.004 ev neutrons scattered at 90° are reported and interpreted in terms of an Einstein model for the proton vibrations with a fundamental frequency corresponding to 0.056 ± 0.002 ev. From this the root-mean-square displacement of the protons relative to the palladium sublattice at room temperature is estimated to be 0.22 ± 0.02 ev, in agreement with the values found by diffraction. The cold neutron scattering data also give information about the heat motion of the palladium atoms. Interpreted on a Debye model they yield a Debye temperature of 300 ± 25°K and a root-mean-square displacement of 0.10 ± 0.01 A.

38. Neutron Diffraction Studies of the Zirconium-Deuterium System.* S. S. SIDHU, LEROY HEATON, AND M. H. MUELLER, *Argonne National Laboratory.*—Neutron diffraction studies of the zirconium-deuterium system have been made in the composition range from $ZrD_{0.02}$ to $ZrD_{1.95}$, with major emphasis on the zirconium-rich region to determine the solid-gas reaction mechanism by which the metal transforms to a deuteride. It is shown that in the composition range $ZrD_{0.02}$ to $ZrD_{0.08}$ a distinct deuteride (γ) is formed, which coexists with the metal (α-Zr). As the concentration of deuterium in the metal is increased, the well-known cubic phase (δ) of this system is formed, and, in the composition range $ZrD_{0.1}$ to approximately ZrD, α-Zr, γ, and δ phases coexist. In the composition range ZrD to $ZrD_{1.52}$, γ and δ phases are present and, in the $ZrD_{1.52}$ to $ZrD_{1.60}$, only the δ phase. A sample containing both γ and δ phases, when heated to about 300°C, transforms to a single δ phase. These results show that α-Zr transforms to the γ phase rather than to the δ phase as commonly reported. It is the γ phase that transforms to the δ phase. Work on the structure determinations of the γ phase by combined neutron and x-ray diffraction methods will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

39. Atomic Positions and Thermal Motion in $FeSiF_6\cdot6H_2O$.* WALTER C. HAMILTON, *Brookhaven National Laboratory.*—Iron fluosilicate hexahydrate has a structure consisting of SiF_6^{--} octahedra at the corners of the rhombohedral unit cell and $Fe(H_2O)_6^{++}$ octahedra at the body centers. A neutron diffraction investigation has been undertaken primarily to determine the exact configuration of the water molecules surrounding the metal ion. At the present stage of the investigation, it appears that the water molecules lie on mirror planes in space group $R\bar{3}m$ with the lone pair orbital directed accurately toward the metal ion. The SiF_6 octahedra are disordered in a simple way. It is hoped that accurate values for bond lengths and thermal vibrational parameters will be available for presentation.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

40. Crystal Structures of Some CaC_2-Type Metal Dicarbides. MASAO ATOJI, *Institute for Atomic Research and Department of Chemistry, Iowa State University.*—The complete-matrix least-squares treatments on the polycrystalline neutron diffraction data of an isomorphous series, CaC_2, YC_2, LaC_2, CeC_2, TbC_2, YbC_2, LuC_2, and UC_2 yielded the C–C distances in the C_2 groups as, respectively, 1.191 ± 0.009 A, 1.275 ± 0.002 A, 1.303 ± 0.012 A, 1.283 ± 0.004 A, 1.293 ± 0.009 A, 1.287 ± 0.009 A, 1.276 ± 0.012 A, and 1.340 ± 0.007 A. The analyses on the paramagnetic, thermal, and other incoherent neutron diffuse scatterings revealed that all metal atoms are in the trivalent ground states, except Ca (divalent) and U (tetravalent), and that the effective nuclear charges obtained for the 4-f electrons in the rare-earth dicarbides are 20 to 30% higher than the Pauling-Slater values. The coherent neutron scattering amplitudes of Ce, Tb, Yb, and Lu have been determined using the absolute neutron diffraction data of CeC_2, TbC_2, Yb, and Lu metals, Yb_2O_3 and Lu_2O_3. They are: $b(\mathrm{Ce})=0.482\pm0.006$, $b(\mathrm{Tb})=0.756\pm0.020$, $b(\mathrm{Yb})=1.262\pm0.012$, and $b(\mathrm{Lu})=0.730\pm0.020$, all in Fermi units. The neutron data were obtained at the Oak Ridge National Laboratory through the courtesy of Dr. H. A. Levy. The crystalline samples were prepared by Dr. A. Daane's group in Ames.

41. Neutron Diffraction Study of $MnCl_2\cdot4H_2O$. W. E. GARDNER, *AERE, Harwell.*—A preliminary report is given of the proton positions in $MnCl_2\cdot4H_2O$ determined by neutron diffraction measurements at room temperature on a single crystal. Both (*hol*) and (*hko*) reflections have been obtained, and the results interpreted using Fourier and least square methods. The environment of the oxygen atoms suggests that the water molecules will have the same form as in steam. The results, however, imply not only a disordered proton arrangement but also unusual bond angles or bond lengths.

42. Single-Crystal Neutron Diffraction Study of $Sr(OH)_2\cdot8H_2O$. WILLIAM R. BUSING AND MARCELLO ZOCCHI,* *Oak Ridge National Laboratory.*†—Neutron diffraction intensities have been measured for 224 reflections of the *hhl*, *hOl*, and *hkO* zones of $Sr(OH)_2\cdot8H_2O$. The results are consistent with the x-ray structure reported by Smith[1] and a preliminary least squares refinement of the parameters, assuming that isotropic temperature factors gave a discrepancy factor of 20% in F^2. The x-ray study did not locate the Sr atom unambiguously, but the present work shows the position postulated by Smith to be correct. Each water molecule is hydrogen-bonded to a hydroxide ion and to another water molecule. The hydroxide ions are hydrogen-bonded to each other in linear chains.

* Guest scientist from Comitato Nazionale per le Ricerche Nucleari, Rome, Italy.

† Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

[1] H. G. Smith, Acta Cryst. 6, 604 (1953).

43. Deformations in Perovskites Containing Rare Earths. F. FORRAT, *Centre d'Etudes Nucleaires, Grenoble.*—The parameters a, b, c of orthorhombic perovskites containing rare earths are plotted vs the average distance oxygen—rare earth. The effect of the lanthanide contractions is a deformation of the lattice. The object of this study is to show that the deformation is *not* linear, in disagreement with earlier findings.

44. Anomalous Neutron Scattering in α-CdS. S. W. PETERSON AND H. G. SMITH, *Oak Ridge National Laboratory.*—Coherent neutron scattering amplitudes are normally assumed

to be real and not energy sensitive. Breit-Wigner dispersion theory indicates, however, that in the neighborhood of a neutron resonance the scattering amplitude is complex and the above conditions would not hold. Observation of the effect of anomalous scattering near a resonance is conveniently made by observing Bragg scattering from (hkl) and $(\bar{h}\bar{k}\bar{l})$ mates which, according to Friedel's law, should give equal intensities, but which in the case of noncentrosymmetric crystals containing complex scatterers become unequal. Recent neutron scattering measurements on hexagonal cadmium sulfide have shown striking evidence of Friedel's law failure. Measurements at several wavelengths confirm that the effect is strongly energy sensitive. The preliminary results are in good qualitative agreement with the Breit-Wigner formulation.

Session VI. Inelastic Neutron Scattering Effects

45. Small-Angle Scattering of Neutrons by Spin Waves. R. D. LOWDE AND N. UMAKANTHA, *Atomic Energy Research Establishment, Harwell.*—Neutron small-angle scattering by spin waves in iron has been observed in virtual isolation at an intensity of several thousand counts per minute. The theoretical dependence of the scattering intensity on neutron wavelength and scattering angle and on specimen temperature, setting, and magnetization has been confirmed. If iron be regarded as a Heisenberg-Bloch ferromagnet, the cutoff angle of the scattering gives a value of 0.018 ev for the effective exchange integral, in agreement with the value obtained by fitting a $T^{\frac{3}{2}}$ law to the saturation magnetization at low temperatures. The usual complication of phonon scattering has been avoided by measuring the intensity at positions close to the main beam. Here l-magnon inelastic scattering is allowed, but there is no l-phonon scattering of neutrons having velocity less than that of sound in the crystal (i.e., in iron, of neutrons with wavelength >1.1 A). As the temperature was raised, it was found that a markedly nonlinear increase of the spin-wave intensity sets in abruptly at $\sim$346°K, which can be shown to be unconnected with phonons, multiple-quantum scattering, multiple scattering, or crystal defects nor is it explained by a temperature variation of J_{eff}. It would thus appear that a moderately excited spin system possesses states that have not hitherto been discussed adequately.

46. Study of Magnetic Interactions in α-Fe_2O_3 and Fe_3O_4 by Neutron Diffuse Scattering in the Spin Wave and the Critical Temperature Region. TORMOD RISTE, *Institutt for Atomenergi, Kjeller, Norway.*—The geometry and the intensity of the diffuse peaks near the (111) reflections of α-Fe_2O_3 and Fe_3O_4 are studied for different settings of the crystal away from the Bragg position. The observations at temperatures well below the Curie points reveal the appropriate dispersion relations for the two cases. In this way a certain linear combination of the exchange integrals is derived for each of the crystals. If only the supposedly strongest interactions are taken into account, the values $-3.5\cdot10^{-3}$ ev and $-2\cdot10^{-3}$ ev of the exchange integrals in α-Fe_2O_3 and Fe_3O_4, respectively, are obtained. By similar experiments in the critical region the range of the spin fluctuations is determined. A molecular field calculation shows that this range is very sensitive as to which interactions are being active. In the case of α-Fe_2O_3 the experimental value of the correlation range is not inconsistent with what one should expect from the interaction model predicted by Gilleo. In Fe_3O_4, however, the observed value of the correlation range is longer than the interactions may reasonably account for. This discrepancy will be discussed.

47. Neutron Energy Distributions at Constant Momentum Transfer. B. N. BROCKHOUSE, *Chalk River Laboratories.*—The natural independent variables in neutron scattering are the momentum and energy transfers, defined by $\hbar\mathbf{Q}=\hbar(\mathbf{k}_0-\mathbf{k}')$ and $\hbar\omega=E_0-E'$, where E_0, E', $\mathbf{k}_0$, $\mathbf{k}'$ are, respectively, the incoming and outgoing neutron energy and wave vector. If the distribution of outgoing energy is measured in the usual way at fixed incoming energy, angle of scattering (ϕ), and specimen orientation (ψ), then $\mathbf{Q}$ varies with E' and thus with ω, an undesirable situation since $\mathbf{Q}$ cannot be preselected. A triple axis neutron spectrometer has been constructed, in which E_0, E', ϕ, ψ are independently, electrically controlled. For given E_0, $\mathbf{Q}$, and a range of values of E', values of ϕ and ψ are calculated on a computer and adjusted nonlinearly in step with the angle of the analyzing spectrometer, that is, with E', in such a way as to preserve $\mathbf{Q}$ constant at its predetermined value. A useful alternative procedure is to hold E' constant and vary E_0, ϕ, ψ nonlinearly as before. This latter procedure has the important advantage that no corrections for instrument sensitivity are required if a $(1/v)$ monitor is used in the incoming beam. The methods have already proved very useful in studies of crystal and liquid dynamics. The spectrometer and control units were largely designed by W. McAlpin and E. A. Glaser, respectively, and Miss M. Millican wrote the computer programs.

48. Lattice Vibrations of Alkali Halides. A. D. B. WOODS, B. N. BROCKHOUSE, W. COCHRAN, M. SAKAMOTO, AND R. N. SINCLAIR, *Chalk River Laboratories.*—We have continued experiments on the alkali halides[1] and have measured dispersion relations for the [100], [111], and [110] directions in KBr at 90°K and 400°K, using the constant momentum transfer method (preceding abstract), with special attention to the optical branches. The frequencies (units 10^{12} cps) of some typical phonons at 90°K are: LO [0,0,0] 5.06; TO [0,0,0] 3.61; LO [1,0,0] 4.05; TO [1,0,0] 3.74; LO $[\frac{1}{2},\frac{1}{2},\frac{1}{2}]$ 4.40; TO $[\frac{1}{2},\frac{1}{2},\frac{1}{2}]$ 3.09; LA [1,0,0] 2.19; LA $[\frac{1}{2},\frac{1}{2},\frac{1}{2}]$ 2.85; TA $[\frac{1}{2},\frac{1}{2},\frac{1}{2}]$ 2.23. Errors are less than 2%. The measurements are in reasonable agreement with calculations[1] on the "shell" model. The frequencies of transverse optic phonons show an almost constant decrease of 7.5% in going from 90°K to 400°K. The frequencies of longitudinal phonons decrease by smaller amounts. Except for the LO branches, little broadening of the neutron groups occurred at the higher temperature. The LO phonons of long wavelength, however, show considerable broadening even at 90°K. The transverse and longitudinal optical frequencies at $q=0$ are observed to be in satisfactory agreement with the well-known relation $\nu_L/\nu_T=(\epsilon_0/\epsilon)^{\frac{1}{2}}$ where ϵ_0, ϵ are the static and high-frequency dielectric constants.

[1] A. D. B. Woods, W. Cochran, and B. N. Brockhouse, Bull. Am. Phys. Soc. Ser. II, **4**, 246 (1959); Phys. Rev. (to be published).

49. Diffusive Motions in Water and Cold Neutron Scattering.* K. S. SINGWI† AND ALF SJÖLANDER, *Argonne National Laboratory.*—By use of a model of liquid water in which a molecule, in its equilibrium position, performs an oscillatory motion for a mean time τ_0 and then diffuses by continuous motion for a mean time τ_1, and repeats this sort of motion, the differential scattering cross section for cold neutrons has been calculated. It is found that the shape of the "quasi-elastic" scattering is, in general, not Lorentzian. A general formula for the broadening of the quasi-elastic peak is given, which has a simple form in the two limiting cases: (a) $\tau_1\gg\tau_0$ and (b) $\tau_1\ll\tau_0$. The observed value of the broadening can be explained for a value of $\tau_0=4\times10^{-12}$ sec. Inelastic scattering of cold neutrons

has been calculated using two different models of water: (a) a gas model and (b) a Debye model, and the results have been compared with experiment. The general shape of both the "quasi-elastic" and inelastic scattering of cold neutrons and the magnitude of the diffusive broadening seem to support a quasi-crystalline model of water.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from the Atomic Energy Establishment, Trombay, Bombay.

50. Inelastic Scattering of Slow Neutrons from D_2O Using a Phased Rotor Velocity Selector. S. J. COCKING,* P. A. EGELSTAFF,* AND I. M. THORSON, *AECL, Chalk River.*—Bursts of nearly monoenergetic neutrons have been selected from a beam from the NRU reactor using two phased rotors with curved slots rotated at up to 36 000 rpm. Two further rotors are phased to close the beam to epi-cadmium neutrons. The time-of-flight of the neutrons after scattering by a thin sample is measured over a flight path of 1.3 m. Ten detectors at angles of scatter from 14° to 150° record simultaneously. The results on heavy water taken with incident energies of 0.035 ev, 0.10 ev, and 0.14 ev will be presented. Graphite and light water also have been studied. The results at all incident energies have been summarized using Van Hove's[1] suggestion that the differential scattering cross section can be expressed in terms of momentum and energy transfers. The results for small momentum transfers are compared with calculations assuming a diffusive motion of the scattering molecules. For large momentum transfers the results cannot be fitted using a "perfect gas" model with a unique scattering mass.

* AERE, Harwell.
[1] L. Van Hove, Phys. Rev. **95**, 249 (1954).

51. Phonon Frequency Distribution in Graphite. P. A. EGELSTAFF, *AERE, Harwell.*—Inelastic neutron scattering measurements on graphite at room temperature and 600°C have been made with the "Scattering Law Apparatus" at Chalk River. The measurements were made at neutron energies of 0.03 ev, 0.07 ev, and 0.14 ev and for a range of scattering angles between 14° and 150°. These data have been analyzed in such a way that the first term of the incoherent approximation mass expansion of Placzek[1] is isolated. The frequency distribution is readily obtained from this term and is compared to the calculations of Baldock.[2] The agreement between experiment and theory is moderate.

[1] G. Placzek, Phys. Rev. **86**, 377 (1952).
[2] G. R. Baldock, Phil. Mag. **1**, 789 (1956).

52. Linac Measurements of H Bonding Effects on Thermal Inelastic Scattering. A. W. MCREYNOLDS AND W. L. WHITTEMORE, *General Atomic.*—Although the earliest work on neutron diffraction and thermal inelastic scattering was done with accelerators, this research in the past 15 yr has been almost exclusively with reactors. An alternative neutron source is now provided by high current pulsed linear electron accelerators. Bombardment of heavy targets produces pulses of 10^{10} or more neutrons, giving flux intensity for periods of a few microseconds comparable to chopped reactor beams and suitable for time-of-flight thermal inelastic scattering studies. Advantages relative to reactor sources are ready accessibility of the neutron source region, unrestricted space for equipment installation, lower gamma heating and neutron activation, and absence of fast neutron background between pulses. Experimental arrangement and operating characteristics and experience are described for a system of a Linac source and 256-channel analyzer developed for this purpose. It has been used initially to study ZrH total cross section over the range 0.001–0.4 ev. As previously shown, the data are well represented by an Einstein model from 0.4 ev to well below the 0.13 ev optical level. A Debye model fits the low energy data well. Neutron spectra from moderating sources of H_2O, CH_2, CD_2, and BeO at temperatures of 300°K and 4°K have been studied to investigate optimum arrangement for cold neutron sources, and further studies continue.

Session VII. Instruments and Techniques

53. Magnetic Space Group Considerations. J. D. H. DONNAY, *The Johns Hopkins University.*—The symmetry of some magnetic crystals cannot be described by the 1421 black-white or colorless space groups, which correspond to one-dimensional irreducible representations of the 230 Fedorov-Schoenflies groups: representations of dimensionality greater than one, which cannot be expressed by color symbolism, also must be considered. Let magnetic atoms occupy the nodes of a lattice *sensu stricto*, i.e., the termini of the vectors $\mathbf{L}(uvw) = u\mathbf{a}+v\mathbf{b}+w\mathbf{c}$, with u, v, w all integers. Let the spins be parallel to a plane (say, **ab**) but lie in different azimuths $(u+v+w)\phi$, with $\phi = 2\pi k$, k irrational, at the various nodes. The cryptosymmetry operation is a translation $\mathbf{L}(uvw)$ combined with simultaneous rotations of all the spins about parallel axes. For rotations of $(u+v+w)\phi$ the group is infinite but contains no translations. For rotations of $(u+v)\phi$ or $w\phi$, it contains the translations of the row $w\mathbf{c}$ or of the net $u\mathbf{a}+v\mathbf{b}$, respectively. The latter case is known in $MnAu_2$ (Mériel-Herpin) and in holmium (Koehler *et al.*). Further generalizations must heed the fact that a lattice complex (occupied by equivalent atoms) does not necessarily possess the configuration of a lattice.

54. Ordered Spin Configurations. E. F. BERTAUT, *Laboratoire d'Electrostatique et de Physique du Metal—Institut Fourier, Grenoble.*—Two simple methods are described to find ordered spin configurations. In the first one, the exchange energy is directly written as a function of angles made by interacting spins and subject to the constraint that each spin "sees" the same neighborhood. This direct method confirms the results already known from the Gersch and Koehler method but also the new ones of spiral modes, found by Yoshimori and Villain in Bravais lattices. The second method uses the fact that, in all magnetic structures, spins have the same phase in planes which are normal to a propagation vector **k**. The exchange energy expressed as a function of **k** is minimized with respect to **k**. This method applied to spinels yields Néel's classical results of subdivision into 2 sublattices but predicts also new modes with lower energies than the Yafet-Kittel modes for a certain choice of exchange integrals. Applications to garnets and other structures and the influence of anisotropy energy are discussed too.

55. Extinction Effects in Magnetized Single Magnetic Crystals.* WALTER C. HAMILTON, *Brookhaven National Laboratory.*—The two spin components of a neutron beam may be attenuated in different amounts by the processes of primary and secondary extinction in reflection from magnetic crystals.[1] In particular, in a single crystal with a unique orientation of the magnetic field, this effect leads to greater extinction for reflections with both nuclear and magnetic contributions to the scattering than for either pure nuclear or pure magnetic reflections. If the magnetic field is not perpendicular to the scattering vector, the precession of the neutron spin about the

magnetic field direction can lead to both an enhancement of the diffracted intensity and a periodic variation of the intensity and polarization with field strength. Some differential equations describing this effect have been presented in a previous communication.[1] These equations now have been solved numerically for various values of the intensities, fields, and scattering directions. The results indicate that the effect may be useful in obtaining information about the average magnetic field strengths in the interior of crystals, as well as information as to the size of mosaic blocks or magnetic domains. Some experimental confirmation of the results on single crystals of magnetite will be presented.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. C. Hamilton, Acta Cryst. 11, 585 (1958).

56. Twin-Rotor Mechanical Neutron Velocity-Selector. R. F. Dyer, G. G. E. Low, and R. D. Lowde, *AERE, Harwell.*—A description is given of the twin-rotor velocity-selector in operation at the Harwell reactor PLUTO. A neutron beam from a source block emitting 4×10^{13} neutrons cm^{-2} sec^{-1} passes through a fast-neutron and γ-ray stopper consisting of a 12-in. length of bismuth single crystal and a 3-in. length of beryllium single crystal and falls successively upon two 10-in. diam rotors fabricated from a Mg-Zr-Cd alloy whose centers may be adjusted to a range of separation distances from 14.5 in. to 24.0 in. The incident collimation angle may be varied between 14′ and 1° 0′ in both vertical and horizontal directions. The rotors are spun[1] at angular velocities up to 500 rev sec^{-1}, and their relative phase is controlled to within a tenth of a degree. Some few million neutrons sec^{-1} fall upon a specimen area of 2×1 cm^2 with a wavelength that at present may be varied down to 2.8 A and with a wavelength resolution that may be fixed at any desired value within a factor of about four on either side of the standard setting of 3.4%.

[1] P. A. Egelstaff *et al.*, Proc. Inst. Elec. Engrs. (London) (to be published).

57. Neutron Diffraction Facility at the Westinghouse Testing Reactor. W. J. Takei, B. C. Frazer,* and G. Shirane, *Westinghouse Research Laboratories.*—The Westinghouse Testing Reactor is a water-moderated, enriched uranium reactor which is expected to have a thermal neutron flux of over 10^{14} neutrons/cm^2 sec and a fast neutron flux of the same order of magnitude at a power level of 60 megawatts. A neutron diffraction facility has been installed at the beam hole of this reactor. A spectrometer, suitable for most diffraction experiments with provision for automatic program control, has been designed. The high nonthermal flux has necessitated large shutters and shields and led to the installation of a D_2O moderating system. These units will be described, and the results of tests made with the reactor operating at 20 megawatts will be discussed.

* Now at Brookhaven National Laboratory.

58. The Livermore Neutron Diffraction Spectrometer.* Warren Mead and Joseph T. Sparks, *Lawrence Radiation Laboratory, Livermore.*—The Livermore powder diffraction neutron spectrometer is designed to provide a versatile, automatic instrument for solid state investigations at relatively low cost. Adjustable collimators with removable septa are located in front of the monochromating crystal and the BF_3 detector, and between the crystal and the sample position. The 6-ft spectrometer arm is supported and driven by phenolic wheels attached to the arm about 50 in. from the central pivot. The angular position of the arm is measured to 0.01 deg by means of a *Datex* digital encoder geared to a curved rack 45 in. from the axis of rotation. In operation the spectrometer arm moves in discrete steps of 0.05 deg or more. At each position, the main counter is gated on for a preset number of monitor counts. At the end of the count, the arm position, time of day, sample temperature, and the counts in both counters are recorded by a *Systron* printer. The counts, as a function of position or temperature, are displayed with an $x-y$ plotter.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.

59. The ORNL Neutron Diffractometer for Magnetic Studies. E. O. Wollan, M. K. Wilkinson, W. C. Koehler, J. W. Cable, and H. R. Child, *Oak Ridge National Laboratory.*—The equipment now in use at the Oak Ridge reactor is very similar to that which has been used at the graphite reactor for several years. It includes a low-temperature cryostat for both powder and single-crystal studies which is built as an integral part of a magnet assembly for applying fields to the sample. The magnet is mounted so as to allow rotation about a horizontal axis through the sample. This flexibility permits the field to be applied at any angle with the scattering vector even at low temperatures. The cryostat moves from 45° on one side of the magnet axis to 45° on the other side as the field vector is rotated through 90°. The magnet gives fields of 21 koe with 7.5 kw and a ½-in. pole separation. Other features of the diffraction equipment such as the crystal monochromator and the recording circuitry will be discussed briefly.

60. Automatic Single-Crystal Orienter for Three-Dimensional Data Collection. H. A. Levy, *Oak Ridge National Laboratory.*—A device is described for automatic orientation of monocrystals in response to punched tape input of angle information. Two crystal rotations are provided: one about an axis in the plane of incidence perpendicular to the scattering vector, and a second about an axis in the normal plane to the first axis. These are adjusted to bring a desired reflection into Bragg orientation in the zero level of a modified General Electric spectrogoniometer. Both rotations are driven by small dc motors and monitored by shaft-encoding devices (digitizers). The precision of both adjustments is 0.01 deg. Each rotation is driven at high speed until recognition is achieved for the most significant digits of the desired angle; then the motor is driven at slow speed in the reverse direction until complete recognition is achieved. Completely transisterized control circuitry is provided. A similar digitizer is provided for positioning the $\theta-2\theta$ coordinate of the spectrogoniometer. Data are collected by step-scanning through the Bragg orientation; for this purpose, either the $\theta-2\theta$ coordinate or the crystal rocking angle may be chosen. Output of data is by means of punched tape, with auxiliary numerical and analog available. Preparation of the input tape and processing of the output tape is to be done by means of the ORNL electronic computer, the ORACLE.

61. Temperature Controller for Neutron Diffraction Studies. D. G. Henshaw, *Chalk River Laboratories.*—For liquid, solid, and magnetic studies by neutron diffraction, the specimens to be studied must be controlled and maintained at a preset temperature for considerable periods. For measurements at low temperatures, two requirements must be met. First, the heat transfer between the specimen and the refrigerant must be high for rapid cooling of the specimen while the second is that the heat transfer during the operation of a controller must be small owing to the small heat capacity of the low-temperature refrigerants. A temperature controller has been built[1] and will be described. This incorporates a "heat switch" which permits the thermal contact between the specimen and the refrigerant to be altered markedly. The temperature of the specimen is maintained and controlled in the range 1.2°K to 400°K by a temperature regulator based on the design due to Dauphinee.[2] With the use of liquid helium as the refrigerant it is possible to maintain a temperature of 30°K with a power of <0.2 w supplied to the heater winding. To cool a specimen from liquid nitrogen to liquid helium temperature, the time required is small, being about 10 min.

[1] D. G. Henshaw, Phys. Rev. 111, 1470 (1958).
[2] T. M. Dauphinee, Can. J. Phys. 31, 577 (1953).

Minutes of the Spring Meeting of The Ohio Section of The American Physical Society, Held at Antioch College, Yellow Springs, Ohio, April 22–23, 1960

THE regular Spring Meeting of The Ohio Section of The American Physical Society was held in joint session with E-Section, Physica and Astronomy, of The Ohio Academy of Science at Antioch College, Yellow Springs, Ohio, on Friday and Saturday, April 22–23, 1960.

Friday morning, April 22, was used in viewing and in the rating of the physics projects submitted by High School students of Ohio. This was the final rating of the projects that had survived the weeding out process at the local school, city or county, and the district levels. The quality of these projects was uniformly high, and about one-fourth of the Section's membership were on hand to help in these final ratings. The physics category continues to be a very large fraction of the projects; in this case the number was 183.

The Friday afternoon program of invited papers was built upon reports and contributions from industrial laboratories. Dr. Carl Kenty, of General Electric Company's Nela Park Lamp Laboratory, Cleveland, gave a paper on, "Excitation of Metal Vapors by Metastable Nitrogen Molecules and Atoms." Dr. Kenty's talk was illustrated by many gaseous discharges not familiar to many of the group. The second paper, by Mr. C. D. Coy, of The Cincinnati and Suburban Bell Telephone Company, Cincinnati, Ohio, was concerned with "The Engineering Society of Cincinnati Looks at Career Guidance in Engineering Science, Mathematics and Physics." This Society has a real program and has had some valuable experience, doing a great deal in this guidance area. Mr. Ron Weirick gave the third invited paper and spoke on, "Fundamental Ideas of Plasma Physics." Mr. Weirick comes from the Laboratories of Thompson-Ramo-Woolridge, in Cleveland, Ohio. The final invited paper, "Physics of the Eye and of Vision," was presented by Mr. Allen E. Murray, Eastman Kodak Company, Rochester, New York. Another invited paper from the Thompson-Ramo-Woolridge Laboratories was on the schedule, "The Development of Ion Thrust," by Dr. Park French, but was eliminated by the fact that Dr. French was not able to be in Ohio in time for our meeting. We hope to hear him some time in the future.

Saturday morning, April 23, was devoted to contributed papers, the first being an historical sketch calling attention to the formation of Science Groups in Ohio, and especially to the physics organizations, which later became a section of the Ohio Academy of Science, and then the development of the Ohio Section of The American Physical Society. Abstracts of the remaining eight contributed papers follow in their order of presentation.

This Spring Meeting includes the election of Officers for the coming year. Officers elected for the year 1960–61 are: Chairman, Dr. Albert B. Stewart, Antioch College, Yellow Springs, Ohio; Vice-Chairman, Dr. John F. Eichelberger, Mound Laboratory, Monsanto Chemical Company, Miamisburg, Ohio; and Secretary-Treasurer, Leon E. Smith, Denison University, Granville, Ohio.

Respectfully submitted,
LEON E. SMITH, *Secretary*
The Ohio Section
The American Physical Society

Contributed Papers

1. Portable Foucault Pendulum. KENNETH WEST, *Mount Vernon High School.*—This paper describes a Foucault pendulum of extremely simple design, accompanied by a full-scale working model with a weight of about 6 lb and a height of about 6 ft. The writer has found the difficulty which causes faulty performance of an ordinary short-length pendulum, namely, imperfections and restrictions at the point of suspension. This difficulty was partly overcome by designing a suspension which can be rotated manually in such a way as to maintain successive swings of the pendulum's pointer over a central point. Then the proper rate of clockwise progression is observed.

2. Shapes of Deformed Nuclei. ROBERT G. WILSON, *The Ohio State University.*—The region of atomic numbers between 150 and 190 is called the region of elliptically deformed nuclei. Nuclei in this region with an odd number of both protons and neutrons may be treated as ellipsoidal, and all known cases are radioactive. The results of investigations of the radioactive decay of some of these nuclei, namely, Tm^{166}, Tm^{168}, Tm^{170}, Lu^{168}, Lu^{170}, Lu^{172}, Lu^{174}, Lu^{176}, which were produced by irradiation of stable enriched isotopes of erbium and ytterbium with 6-ev protons will be presented. Similarities in the energy level schemes of the daughter nuclei which are spherically symmetric in their round states, and an interpretation of the deformations and changes in shape implied by these schemes, will be discussed in terms of rotations, vibrations, pulsations, single-particle transitions, moments of inertia, angular momenta, and quadrupole moments. The ground state spins of these odd-odd nuclei as measured directly or as deduced from the mode of radioactive decay obey remarkably well a simple rule, $\Omega_t = |\Omega_p \pm \Omega_N|$, which will be discussed.

3. Gamma Irradiation of Germanium Diodes under Controlled Ambients. G. J. FREYER, W. METSCHER, AND W. L. LEHMANN, *Air Force Institute of Technology.*—Germanium grown junction diodes, type Western Electric 1784, were decencapsulated and electrolytically etched in weak NH_4OH solutions, rinsed, and vacuum dried. The diodes were then exposed to controlled ambients of oxygen and varying amounts of water vapor, both in and out of a cobalt-60 gamma field of 1.2×10^7 ergs/g carbon-hour. For a dry oxygen ambient under irradiation, the reverse current of a typical diode reached a peak value of 250 μa at 27 v, decreasing sharply to 20 μa at

30 v and higher values of voltage. As relative humidity was increased, the current peak gradually disappeared, with the reverse current saturating at some 100 μa at 100% relative humidity. One diode was cycled at constant voltage from dry to wet oxygen repeatedly. A current in dry oxygen of some 90 μa decreased to approximately 10 μa at 10%–35% humidity before increasing to 200 μa at 100% humidity. Possible explanations are advanced.

4. Limiting Detectivity of Optical Amplifying Equipment. R. K. H. GEBEL AND LEE DEVOL, *Wright-Patterson Air Force Base.*—The limits in the ability to detect very faint stars in the presence of the sky background by conventional photography and by employing optical amplification are investigated and compared in this paper. Equations are developed which show the effects of the different variables involved for three types of imaging systems: the simple photographic system, the image-converter, and the closed-circuit television type of optical amplifier. The last-named system is found to be capable of detecting the smallest differences in brightness.

5. AFIT Nuclear Reactor Simulator. D. L. LUCKE AND W. L. LEHMANN, *Air Force Institute of Technology.*—A nuclear reactor simulator consisting of a passive network assembly and a conventional analog computer has been designed and is under construction. The simulator solves the kinetic equations of a reactor using any desired values of neutron lifetimes, and delayed neutron groups are solved. Procedures for operation, including step and ramp increases in reactivity, positive and negative temperature coefficients, xenon poisoning and scram, shim and regulating rod controls, are described. Heat transfer equations are incorporated into the design. Operations and response for step increase in δk are described.

6. Radiation Resistance of Magnetostrictive-Stack Transducer in the Presence of a Second Transducer at Air-Water Surface.* F. B. STUMPF AND F. J. LUKMAN, *Ohio University.*—The radiation resistance of a nickel magnetostrictive-stack transducer in the presence of an identical in-phase transducer at an air-water surface was obtained. The transducers are resonant at 20 kc, and radiating surfaces are squares with sides 0.38 of the wavelength in water. Curves were obtained for the radiation resistance vs separation distance for interacting source-strength to source-strength ratios of 1.0, 2.0, and 3.9. It was found for a given source-strength ratio the radiation resistance oscillated about the value for the radiation resistance of the source with no interaction and that the oscillations decreased in amplitude as the separation distance was increased. Near 2λ the interaction effect became negligible. Furthermore, it was found that the interaction effect increased with increasing interacting source strength. The interaction resistance was obtained using the equation[1] $R = R_i(D_A - D_L)/(D_L)$, where R is the radiation resistance, R_i the internal resistance, D_A is motional impedance diameter in air, and D_L motional impedance diameter in water. The circuit used to measure these diameters was that of Pigott and Kendig.[2] In order to perform these experiments in a free field, a 30-in.×30-in.×30-in. anechoic water tank was constructed. The tank was lined with aluminum-impregnated butyl rubber wedges in the form of right circular cones 1½ in. high and mounted on a ½-in. backing of this material.

* This work was supported by an Ohio University Research Grant.
[1] F. V. Hunt, *Electroacoustics* (John Wiley & Sons, Inc., New York, 1954), p. 124.
[2] M. T. Pigott and P. M. Kendig, J. Acoust. Soc. Am. **26**, 974 (1954).

7. Investigation of the Anomalous Proton Magnetic Resonance Behavior in Lithium Sulfate Monohydrate.* K. F. WYLIE AND A. A. SILVIDI, *Kent State University.*—A partial proton magnetic resonance investigation of lithium sulfate monohydrate was made by Pake,[1] Soutif and Ayant,[2] and Hirahara and Murakami.[3] The separation between the resonance lines due to dipole-dipole interaction had been predicted and observed for many crystals. McGrath[4] *et al.*, in making a further detailed study of lithium sulfate, discovered an anomalous behavior. The Pake curves, obtained when the crystal was rotated about its crystallographic *a*, *b*, and *c* axes, showed a variable shift in the dipole splitting. An adequate theoretical explanation for these shifts is lacking. This paper will describe the attempt made at an experimental explanation of the shifts. The experiments consisted of examining the proton resonances around the minimum points of the Pake curves at various values of the externally applied magnetic field. It was hoped that the shifts could be related to the external fields. The results which show that the shifts are independent of the external fields will be discussed.

* Partially supported by the U. S. Air Force through the Air Force Office of Scientific Research.
[1] G. E. Pake, Ph.D. Thesis, Harvard University, Cambridge, Massachusetts (1948).
[2] M. Soutif and Y. Ayant, J. Chim. Phys. **50**, C107 (1953).
[3] E. Hirahara and M. Murakami, J. Phys. Soc. Japan **11**, 239 (1956).
[4] J. W. McGrath, A. A. Silvidi, and J. C. Carroll, J. Chem. Phys. **31**, 1444 (1959).

8. Analysis of Hydrogen Isotopes by Mass Spectrometry. K. W. FOSTER AND J. W. BURNS, *Monsanto Chemical Company.*—The analysis of hydrogen isotopes by mass spectrometry is complicated by several mass multiplets that appear in the spectrum. Most commercially available mass spectrometers use electron impact ion sources which give rise to appreciable amounts of monatomic ions. Another complicating factor is the presence of He^3 formed by the radioactive decay of the tritium present. Thus, ten different ionic species are found distributed among the six mass peaks. These include two doublets and a triplet. Many present-day mass spectrometers are not sensitive enough to resolve these triplets; therefore, this paper outlines a satisfactory method of calculating the individual components present in a mass spectrum. The method involves the solution of simultaneous equations containing appropriate pattern coefficients. It has been shown that the formation of monatomic ions by electron impact is quantitatively predictable from the zero-point vibrational amplitudes of the parent diatomic molecules. Therefore, the ratios of pattern coefficients are considered as constant. With appropriate assumptions it is shown how the pattern coefficients can be computed from a single determination of the fragmentation pattern of one of the diatomic species.

MINUTES OF THE SPRING MEETING OF THE NEW YORK STATE SECTION HELD AT COLGATE UNIVERSITY, HAMILTON, NEW YORK, ON APRIL 22 AND 23, 1960

"MODERN Advances in Radio Astronomy" was the title of the symposium which composed the program for the 1960 Spring Meeting of the New York State Section at Colgate University. The titles and speakers for the 15 papers are given below. A selected group of the papers will be published in a future issue of *Physics Today*, together with an informal account of the remainder of the program.

On Friday evening, April 22, the Section shared with the University Community a lecture by Fred T. Haddock of the Departments of Astronomy and

Electrical Engineering, University of Michigan, on "Radio Astronomy Enlarges Our Universe."

The minutes of the Executive Committee meetings and of the Business meeting of the Section are appended.

Symposium Papers

(Presented after a welcoming address by President Everett Case of Colgate)

1. Survey of Contributions of Overseas Observatories to Recent Developments in Radio Astronomy. B. F. BURKE, *Department of Terrestrial Magnetism, Carnegie Institution.*

2. Radio Emission from the Planets. F. D. DRAKE, *National Radio Astronomy Observatory.*

3. Characteristics of Solar Radio Emission. F. T. HADDOCK, *Department of Astronomy, University of Michigan.*

4. Spectral Line Research in Radio Astronomy. A. E. LILLEY, *Harvard College Observatory.*

5. Characteristics of Cosmic Radio Radiation. H. C. KO, *Radio Observatory, Ohio State University.*

6. Modern Theories of the Origin of Galactic and Extragalactic Radio Emission. G. R. BURBIDGE, *Yerkes Observatory, University of Chicago.*

7. Scientific Program for the 600-Foot Radio Telescope at Sugar Grove, West Virginia. E. F. MCCLAIN, *U. S. Naval Research Laboratory.*

8. A Survey Introduction to Masers. E. G. BROCK, *Basic Science Laboratory, Stromberg-Carlson Company.*

9. Application of Masers in Radio Astronomy. B. F. C. COOPER, *Harvard College Observatory.*

10. Radio Astronomical Experiments in Balloons, Rockets, and Satellites. A. E. LILLEY, *Harvard College Observatory.*

11. Radio Astronomy Program at Rensselaer. R. FLEISCHER, *Department of Astronomy, Rensselaer Polytechnic Institute.*

12. A Report on the Velocity Field of the Interstellar Gas. H. L. HELFER, *Department of Physics, University of Rochester.*

13. Solar Radio Observations at Cornell. M. COHEN, *Center of Radiophysics and Space Research, Cornell University.*

14. A Brief Report on the Status of the ARECIBO Radar Observatory. M. COHEN.

By popular request, an additional paper was added here: **A Brief Report on the Scientific Basis for Project "OZMA."** F. D. DRAKE, *National Radio Astronomy Observatory.*

15. Summary of the Meeting and a Look at the Future of Radio Astronomy. B. F. BURKE.

Minutes of the Executive Committee, New York State Section

April 21, 8:30 p.m.

The minutes of the previous meeting at the Hotel New Yorker, January 29, 1960, were read and approved. Arrangements for future meetings were reported by the chairman and vice-chairman. The fall 1960 meeting will be at Harpur College, November 4–5, 1960, on the subject, "Modern Advances in Physical Computing Systems." The spring 1961 meeting will be at LeMoyne College, Syracuse, April 14–15, on the subject, "Cryogenics." The fall 1961 meeting will be at Niagara Falls, New York, under the sponsorship of the Carborundum Company.

Dr. M. V. Smith is giving full attention to the arrangements of the program for the Harpur College meeting, and Dr. K. H. Moore will spearhead the arrangements for the Niagara Falls meeting. Various possibilities were mentioned for the meetings to be held in 1962. The possibilities mentioned were General Electric or Union College, Schenectady. The secretary reported on preparation of a mailing list of industrial and educational institutions in the state with the thought that perhaps much postal expense could be saved by having programs distributed within these organizations rather than mailing to individuals. The members present expressed themselves favorable to this approach and were willing to give it a trial for one of the forthcoming meetings.

Dr. Morey discussed the need for a brochure setting forth the aims and activities of the section, including a membership directory and a copy of the by-laws. He suggested the appointment of a committee to prepare such a publication to be printed and distributed to the membership.

Mr. Miller reported on the results of the ballot on the proposed amendment to enlarge the executive committee by four members. The results were 50 affirmative and 3 adverse votes. In view of the probability that the amendment would be approved by the section on Saturday afternoon, a discussion followed on the appropriate procedure to activate four additional members to begin work as soon as possible. A motion by Dr. Morey, seconded by Dr. Parker, and passed, was to the effect that all members of the executive committee submit at least one possible candidate for an executive committee member to the chairman within four weeks. It was moved by Dr. Hazzard and seconded by Dr. Moore that Dr. Renzema appoint the four additional members as authorized by the amendment to serve on the executive committee until the next regular election. The motion was carried unanimously.

Membership applications for 43 new members were approved. Mr. Miller reported on the present standing of the section, membership and finances. Membership increased during the past year from 342 to 383 members. Bank balance on hand now stands at $719.77. The balance increased by only $11 between October 1, 1959, and April 1, 1960, with receipts of $849 and expenditures of $838.

Mr. Miller reported receipt from Dr. Morey, as a gift to the section, of 10 shares of common stock of Chemetron Corporation on February 5, 1960.

It was moved by Mr. Miller and seconded by Dr. Morey that each member should send Dr. Renzema a summary of the objectives of the section. These statements of our objectives will be used to synthesize a single statement to be used in a proposed brochure.

Dr. Pryor and Mr. Miller reported that they had not yet met to prepare an up-to-date set of the by-

laws for reprinting. Mr. Miller offered to prepare copies for distribution to the executive committee for approval.

Meeting was adjourned at 9:30 p.m.

ORAN E. MILLER
Secretary-Treasurer

April 23, 2:45 p.m.

Dr. Moore reported on plans for transcription of the papers presented at the Colgate meeting. It was decided that Dr. Moore would take the responsibility of contacting the authors and work with them on the most efficient procedure for getting the papers presented at this meeting into a proper form for publication in *Physics Today*. Dr. Moore will then submit these papers to Mr. Miller for transmittal to Mr. Davis, Editor of *Physics Today*. All preliminary contacts with the authors until the papers are ready for publication will be handled by Dr. Moore.

Meeting adjourned at 3:00 p.m.

ORAN E. MILLER
Secretary-Treasurer

Present at both meetings: G. W. Hazzard, O. E. Miller, K. E. Moore, D. R. Morey, C. J. Parker, M. J. Pryor, T. S. Renzema.

Business Meeting, New York State Section

April 23, 1960, 2:30 p.m.

Chairman: T. S. Renzema, Presiding

The minutes of the last annual meeting held at Rensselaer Polytechnic Institute were reported and approved.

The secretary reported on the membership and financial status of the section. A copy of his report is appended to these minutes. The proposed amendment to increase the membership of the executive committee by four additional elected members was approved by 50 affirmative vs 3 negative votes. Dr. Renzema advised the meeting that the executive committee had authorized him to appoint four new members of the executive committee to serve as interim appointees until the next regular election which will be held in the spring of 1961. Dr. Renzema asked for suggestions from the membership on suitable candidates for these appointments. Dr. Renzema also reported on arrangements for the fall meeting at Harpur College at Vestal, New York, November 4–5, on the subject, "Modern Advances in Physical Computing Systems," and the spring meeting, April 14–15, 1961, at LeMoyne College, Syracuse, on the subject, "Cryogenics." An invitation also has been accepted from the Carborundum Company, Niagara Falls, New York, to hold a meeting in the fall of 1961. The subject and date will be announced later. Dr. Renzema then asked for invitations from industrial and educational institutions for future meetings of the section. He pointed out that the section will accept invitations only from organizations or institutions which are strongly interested in having our meetings and whose interest is strong enough to guarantee adequate support on making local arrangements for the meeting. He also stated that the entire program here at Colgate has been recorded on magnetic tape and Dr. Moore has made arrangements to transcribe the recording as a first step toward preparing the proceedings for publication in *Physics Today*.

Dr. Moore, on behalf of the section, expressed deepest thanks to the local committee at Colgate for the tremendous job they have done on arrangements for the present meeting.

All those present warmly praised Dr. Morey for arranging a tremendously fine program for this meeting.

Meeting adjourned at 2:45 p.m.

ORAN E. MILLER
Secretary-Treasurer

MINUTES OF THE 1960 SPRING MEETING HELD AT WASHINGTON, APRIL 25–28

THE 1960 Spring Meeting of The American Physical Society was held at Washington, D. C., on Monday, Tuesday, Wednesday, and the morning of Thursday, April 25–28. "Spring Meeting" and "Washington Meeting" are synonymous in our usage, since for more than half a century there there has been a Spring Meeting at Washington in every year except the war years, and there has never been a meeting in that city at any other time of year except in the now distant times when we were still taking part in the winter convention of the American Association for the Advancement of Science and that Association happened to convene at Washington. Until this year we always assembled on the last three days of the week of which the National Academy of Sciences occupied the first three with the sessions of its Annual Meeting. The extreme stringency of the hotel situation at this popular time of year in Washington has forced us to abandon this sequence and move our sessions into coincidence with those of the Academy. Though most of the members of our Council are Academi-

cians, no complaint was voiced when this necessity became apparent, and it looks as though, by and large, those who belong both to the Society and to the Academy are more than contented to be able to shorten their stay in Washington to four days at the cost of dividing their time between the two conventions. We complied with a request that, on Monday after 3:30 p.m. and on Tuesday morning, the Council should not be in session and Academicians should not be asked to give invited papers or to serve as chairmen at scientific sessions. We complied also with a request that our banquet be held on Wednesday evening instead of Tuesday evening. We suffered no great disadvantage through this degree of compliance, which is a measure of what we can willingly afford to yield in time to come.

The change in dates enabled us to lengthen our meeting to four days, an innovation of which we had stood in need for several years. Owing to the unexpected decline (from last year) in the number of contributed papers, we could afford to occupy only the morning of the fourth day and to leave our members free to enjoy Washington after luncheon: one must not expect that this will recur. Even with this concession, our seven half-days allowed us to reduce to six the number of simultaneous sessions on three of the half-days and hold it at seven on four others; last year there were either seven or eight all the time. The change of dates also leads us to expect cooler weather than heretofore, a consideration not without importance in the Washington Spring. Statistically this should be true, but 1960 was freakish, and the first day of our meeting was impaired by a fierce untimely heat wave while the rest of the week was cool.

The registration was 2052; last year it was 2082, and the previous year it was 1911. The number of contributed papers was 434; last year it was 453 (the record) and the previous year it was 404. These figures betoken fluctuations rather than a trend, but experience suggests that such a period is but the prelude to another upward trend. Of the invited papers it seems invidious to speak of some and not of all, but it may be mentioned that among the speakers were the two most recent Nobel laureates in physics (Owen Chamberlain and Emilio Segrè), the first and latest recipient of the American Physical Society Prize sponsored by Hughes Aircraft Company (Donald Glaser), and the second and latest recipient of the Dannie Heineman Prize (Aage Bohr). Mention will be made hereunder of the paper that was not given.

A strange thing happened, which would have been serious had not our excellent Local Committee had such a winning way with the hotels. Always heretofore the rooms which it had booked for our members had more than sufficed for the demand. This year it had booked more than ever before, and yet the demand exceeded the supply by something of the order of 150, though this year's registration was less than last year's. Somehow or other the gap was bridged, though it seemed unbridgeable. Our members should apply for room reservations earlier than some of them do. If there is again a shortage, then the earlier it is detected the easier it will be to remedy.

It is now high time to call our readers' attention to the debt that we owe to the unremunerated labors of the Local Committee, which serves us year after year with no reward but the sense of a good job well done. R. D. Huntoon was the Chairman of long experience, and the other members of the Committee were D. F. Bleil, W. C. Hall, A. L. Mahan, J. H. McMillen, P. L. Reid, S. F. Singer, L. Slack, G. M. Temmer, and W. R. Tilley: they were drawn from not fewer than eight of the institutions of the Washington area. Messrs. Tilley and Reid and Mrs. Florence Sharkey did vast amounts of work in preparation and seemed during the meeting to be always in the headquarters room or else on errands hither and yon about the meeting places, working like beavers to keep everything going well. We always envy the wives of the members their entertainment, provided this year by a Committee of Washington ladies headed by Mrs. Arthur E. Ruark. It speaks well for the diligence of the men that they do not invade it.

The cocktail party and banquet of the Society were held on Wednesday evening in the Sheraton Room of the Sheraton-Park Hotel. This vast space was far from completely filled, but at least we had 418 in attendance, perhaps a record number and certainly not far from a record number. The after-dinner speaker was L. A. DuBridge, whose prestige may have drawn the crowd and whose speech justified it. The 1960 Dannie Heineman Prize for Mathematical Physics was awarded to Aage Bohr who was present to receive it. Melancholy was infused into the occasion by the tragic fate of C. J. Bakker, the renowned physicist who was Director-General of the great laboratory at Geneva of the Organization Européenne pour la Recherche Nucléaire, universally known as CERN. He was to have been there; he had volunteered to address our meeting on recent progress at CERN. He met his death on April 23 in an airplane accident: it is small consolation to know that the accident occurred on a detour and not on the direct route Geneva-New York-Washington. The President spoke in remembrance of him, and one of our Past Presidents represented us at his funeral in Amsterdam.

The Council met on Monday. It elected to Fellowship 16 candidates and to Membership 424 candidates: their names are appended. The numbers

are greater than is usual at this time of year, for owing to special circumstances there had been no elections at the March meeting. The Report of the Managing Editor heralded the notable feat of publishing the issues of *The Physical Review* near to the dates printed on their covers, which our members will have noted before these lines appear unless some obstacle arises. Essence of the Report of the Treasurer has appeared in the previous (June) issue of this *Bulletin*.

Elected to Fellowship on April 25, 1960: Lawrence C. Biedenharn, James J. Brophy, George A. Cowan, Michael Danos, Narinder Singh Kapany, Elliott J. Lawton, T. D. Lee, Sidney H. Liebson, J. Carson Mark, G. K. O'Neill, Leonard Reiffel, Arnold Russek, Kurt E. Shuler, Arthur Glenn Tweet, Frederick Warren Van Name, Jr., George D. Watkins.

Elected to Membership on April 25, 1960: S. L. Aggarwal, Cardis L. Allen, James Charles Andrellos, Ronald W. Ansevin, Bradshaw F. Armendt, Jr., Donald J. Arnold, Bertrand B. Aubrey, Pierre G. Averbuch, John Dickson Baldeschwieler, Edward J. Barry, Frank Bartro, Jr., John E. Beam, Albert C. Behrenhoff, Alfred Belok, Albert Hugh Berman, William Bernard, Newton Bernardes, Benjamin Tobias Bernstein, Elliott J. Bier, J. W. Blamey, André Pierre Blandin, Giovanni Boato, James E. Boggs, Angus F. Bond, Frederick J. Bornholdt, F. Paul Brady, Alan D. Brailsford, Robert Frank Brebrick, John L. Brewster, Ivor Brodie, Hugh N. Brown, Robert G. Brown, Robert R. Brown, William Maurice Bugg, L. Harold Bullis, Anthony Joseph Bur, Matthew J. Burns, Pierre R. Busquet, Pierre L. Cachon, Umberto Canali, Louis J. Caplan, John A. Cappellini, Thomas J. Carroll, Edward Spencer Cassedy, Jr., Lorne Maxwell Chanin, Cheng-Lin Chen, Fritjot Ernest Christensen, William H. Cloud, David J. Collins, Duane H. Cooper, Ernest F. Costello, Jr., George Couchet, Raymond Albert Daly, Douglas A. Davids, Milford H. Davis, Robert G. Deissler, Anthony Demetriades, Elliott Herbert Diamond, Hillman Dickinson, Roberta Ann di Novi, Arthur Dorne, Donald W. Drawbaugh, Pierre Dumontet, Antoni Dymanus, Robert A. Eckel, Barlane R. Eichbaum, Donald F. Eldridge, A. Cemal Eringen, Arthur J. Estin, Frank F. Fang, Leo G. Faust, Josephine C. Feder, Alonso Fernández, Clarence William Fette, Joseph Anthony Finocchiaro, Helmut J. Fischbeck, Rudolf Fleischmann, Roger Vincent Francis, George A. Franco, David B. Fraser, Robert W. Fredricks, Albert L. Free, Kenichi Fukui, Harry C. Gatos, Denos C. Gazis, David A. Gerlich, Irving Glazer, Bernard Goldberg, Alvin D. Gottlieb, Eugene A. Graham, Jr., Melville Saul Green, John G. Gualtieri, Virendra Gupta, James P. Hamill, Robert F. Hampson, Jr., Edwin H. Harrison, Jr., Robert Hart, Francis James Haughey, William Hayes, Ulrich A. L. Hauser, Lee O. Heflinger, Alan G. Henney, Sheldon B. Herskovitz, Akira Hirai, Robert Lawrence Hittleman, Sandor Holly, John W. Hooper, Robert E. Huffman, Herbert Eugene Hungerford, Jack E. Hunsicker, Yasumasa I'Haya, Herbert S. Ingham, Reilly C. Jensen, Kent R. Johnson, Richard M. Josephs, Coleman Kaplan, Clement Anthony Karolak, Toshio Katoh, Herman S. Kaufman, Irwin A. Kaufman, David G. Keiffer, Charles H. Keller, Jack L. Kerrebrock, David F. Keyes, Robert F. Kiddle, Tracy S. Kinsel, John P. Kittel, Masatoshi Koshiba, Kramer Gustav, William Franklin Krupke, Bjorn N. A. Lamborn, Reginald E. Larson, Edward L. Lee, Panos A. Ligomenides, Ingvar P. K. Lindgren, Albert L. Loeffler, Jr., Wellington H. T. Loh, Olli V. Lounasmaa, Roland W. Lovejoy, Albert G. Lutz, Cesare Marioni, Troy C. Martin, Shiro Matsuoka, Richard L. McGuire, Robert G. McIntyre, Carver A. Mead, Jagdish Mehra, Dickron Mergerian, H. Harvey Michels, Willem C. Middelkoop, Perry A. Miles, Wendell D. Miller, Rudolf L. Moessbauer, Janes C. Morris, Douglas R. O. Morrisson, Robert W. Moss, Herbert J. Mueller, George M. Muha, James A. Mullen, Robert Frederick Muller, Lawrence Kevin Murray, Berry H. Nall, Vernon Duane Neff, G. Newmark, Robert Ernest Odening, Michael F. O'Dwyer, William J. Offutt, Robert J. Omohundro, William C. Orthwein, Douglas R. Paden, M. B. Palma-Vittorelli, B. Robert Parnes, Jamshed R. Patel, Maung Hla Pe, Carl E. Pearson, Neal F. Peek, Robert W. Peer, Elam Pitkjaan, W. J. Popelbaum, Dan I. Porat, Vasant R. Potnis, Werner R. Rambauske, Maxwell Ratner, Michael W. Rice, W. D. Richey, Lyle G. Riffee, Wayne K. Rivers, Jr., H. David Rix, Raymond A. Robertson, T. J. Rock, Martin L. Rossi, Ralph P. Ruth, Richard W. Rymer, Richard G. Saelens, Amrit Sagar, Glenn T. Sakai, Nathaniel L. Sanders, Martin Ernest Sandfelder, Arthur O. Scharmann, Lester M. Schuster, Bertram Schwartz, Manuel Schwartz, Robert Eugene Scott, Jacques P. F. Sellschopp, Steven Serabian, John Charles Sessler, Shiegeo Shionoya, Michael M. Shurman, Donald Robert Simon, Bernard L. Skwirut, Thoma M. Snyder, Rudolf Sommerhalder, Robert Lyon Spurr, Michael J. Stephen, David P. Stern, Sidney H. Sternick, Boris Peter Stoicheff, Hans Juerg Stocker, Ralp L. Streever, Sudarsono, Julius Sunshine, William O. Swan, Jr., Norman M. Tallan, Bruce H. Taylor, Kenneth N. Taylor, Raymond L. Taylor, Hans H. Thies, James Stratton Thompson, Calvin O. Tiller, Yutaka Toyozawa, William D. Twose, Herbert L. Uphoff, Burt C. Veres, F. Lincoln Vogel, Calvin O. Vogt, Raymond L. Ward, Hans Warhanek, Dwight Weber, Herbert Weintraub, Irwin Leigh Weiss, Otto W. Wendel, Lisle L. Wheeler, John Charles Wiesner, John S. Wiley, David Ronald Williams, Philip R. Wilson, Richard W. Wilson, Nathaniel W. Woodrick, John J. Wooldridge, Ralph Frederick Wuerker, Perry P. Yaney, K. C. Yeh, George W. Zepko, Francis P. Ziemba, Ranier Zuleeg.

Elected to Student Membership on April 25, 1960: Ronald Aaron, Stanley Aks, Gerald P. Alldredge, Robert Lowell Anderson, L. Lamar Armstrong, Richard A. Arndt, Charles K. Asawa, D. James Baker, Jr., Pradip M. Bakshi, A. Stanley Barker, Jr., Charles L. Bauer, John L. Baum, Robert A. Beaudet, John Bedrossian, Jr., Larry Warren Bell, Haven E. Bergeson, Davy L. Bernard, Dwijendra L. Bhattacharya, Harold J. Born, James W. Boss, Harry Fred Bowsher, Walton T. Boyer, Jr., Burton Budick, Kurt H. Buerger, Jr., Daniel R. Ch'en, Kuk Pyo Chung, Grover C. Cobb, Jr., Sam Ray Coriell, John G. Cramer, Jr., William E. Crumley, Stephen M. Day, P. Gregory DeBaryshe, Brian Dickens, Larry R. Doyle, Darrell J. Drickey, John R. Dunning, Jr., Paul J. Ebert, Richard McElvain Elrick II, Harold Falk, William Guignard Faris, Luis Mario Flores, John C. Garrison, Claude Garrod, Ira Herbert Gilbert, C. Richard Gillespie, Paul David Goldan, Allen Marshall Goldman, Arthur Greenberg, Newton I. Greenberg, Frederick P. Greenleaf, Emery E. Griffin, Jr., Henry C. Griffin, Peter John Groblicki, Paul S. Grover, Gareth Eugene Guest, Millard A. Habegger, Richard T. Hall, Jeff Hanna, Jr., Bruce W. Hapke, George S. Hayne, Stanley Y. H. Hee, Alan Jay Heeger, Carl Noble Helmick, David L. Hendrie, Sten I. Herlitz, Paul J. Hickson, Virgil L. Highland, Lewis C. Himmell, Robert H. B. W. S. Hobart, Jr., Edward Robert Horton, Stephen Henry Howe, Virgil D. Huber, W. E. Hunt, Adeshwar Preshad Jain, Thomas George James, Ron A. Javitch, Joseph A. Johnson, III, Earl Walter Johnston, Gerald Lee Jones, Norman Eric Jorgensen, Richard Isaac Joseph, Sanehiko Kakihana, Paul B. Kantor, Joseph L. Katz, Alfred M. Kaufman, John F. Kenney, Daniel Richard Killoran, Mark Phillip Klein, William J. Kossler, Harry Kroger, Peter C. Landry, John Edward Lawrence, Edward I. LeBaron, Robert W. Lee, Harvey S. Leff, John S. Lew, Richard Leo Linster, Lawrence Mark Lidsky, Thomas Walter Listerman, Billy Jack Marshall, Donald G. McDonald, Robert H. Meichle, Paul Meyer, Ralph O. Meyer, Catalin D.

Mitescu, Stanley P. Morris, James L. Morrison, Richard L. Morse, Kenneth Gerald Moses, George T. Mulholland, Robert A. Myers, Prakash S. Nangta, Musti Appala Narasimham, Uriel Nauenberg, Chandra P. Nehra, James B. Nelson, Christopher Y. Ng, Martin G. Olsson, Robert Salvatore Panvini, Joseph C. H. Park, James M. Peek, Joseph L. Percy, Jr., Pharo A. Phelps, Richard J. Pleitt, Donald B. Polatty, Donald A. Pritchard, Shelden H. Radin, Charles E. Ramer, L. Kasturi Rangan, William J. Reilly, Edgar Allen Rinehart David B. Robinson, Stephen D. Rothleder, Donald Sashin, Harold J. Scheinhaus, Dan W. Schlitt, Ivan G. Schroder, H. Alan Schwettman, Julius Shain, Robert E. Shamu, James A. Shannon, Carl Richter Shonk, Peter D. Skiff, Donald R. Smith, Robert L. Smith, Harold N. Spector, Stanley L. Spiegel, Carl V. Stager, Harold M. Stahl, John D. Stettler, Edward C. Stone, Jr., Donald Lawrence Strandburg, Raymond E. Sund, Maury Tigner, Morton Louis Topfer, Murray Turoff, Leonard M. Valley, William E. Vehse, Hans C. Von Baeyer, Robert Gordon Wagner, Russell E. Walstedt, Carl F. Weissfloch, Karl J. Wetzel, Martin H. Wilner, Kent R. Wilson, Richard C. Wingerson, Sinclair Shee-Sing Yee, Shoichi Yoshikawa, Robert Eugene Zier, James J. Zwolenik.

Elected to Membership as of July, 1960, by the "alternative scheme" authorized in Article IV, Section 1, of the Constitution: Manlio G. Abele, Marvin S. Abrahams, Charles Q. Adams, George DeWitt Adams, Thomas Leland Aggson, Joachim Cordt Appel, Robert U. Ayres, Claude C. Barnett, Walter R. Beam, Andrew J. Beck, Jr., Donald Julius Belknap, William Thomas Berg, Giancarlo Bertolini, Martin H. Bloom, Edmund Brigmanis, Henry S. Burden, Eugene Butkov, Thomas Cantwell, Richard Charles Carlston, Louis S. Castleman, Bansun Chang, Dudley Boyd Chelton, Leonard V. Cherry, Arthur E. Clark, Richard Francis Cornelissen, Howard L. Daley, Graham Derrick, Luis G. DeSobrino, Walter Franklin Dimmick, Pieter S. Dubbeldam, Robert C. Duncan, Jr., Byron N. Edwards, Samuel Adams Elder, Larry Flax, Daune M. Gall, Philip Goldberg, Roger D. Griffioen, Norman E. Hansen, Isidore Hauser, Audrey Joan Hebling, Robert Edward Henderson, Ross E. Hester, Philip B. Horton, George R. Imperial, Uno Ingard, Adishwar L. Jain, William C. Johnston, Chang Sull Kang, Stanley M. Karandanis, Alfred S. Keh, Bernard V. Kessler, Joseph Vincent Kiernan, Chong C. Kim, Oscar Lloyd King, Sonja Krause, David Langford, Neil L. Lark, Saul R. Lederhandler, Friedrich W. Leonhard, James J. LePage, Edward Levine, Benjamin S. Lowe, Sr., Girard R. Lowrey, Jr., Francois Lurcat, Gerald R. Lynch, Philip James Lynch, Peter V. Mason, Tony Maxworthy, John P. McCormick, Albert E. Metzger, Paul Richard Miller, Abdallah Hazem Mohsen, Thomas R. Moorhouse, John C. Murphy, Mary Jacqueline O'Rourke, Guy Paquette, Elizabeth C. Patterson, Frank L. Pilar, Robert Pomerantz, Joseph Powers, Charles J. Reidl, John Rolfe, F. Elwood Root, Walter Roth, Francis J. Schima, William B. Self, Amiya K. Sen, Keith L. Smith, Edward James Stansbury, Ernest Stern, Robert Murray Stewart, Jr., Rudy C. Stiefel, Robert E. Strakna, Marvin Swartz, Snowden Taylor, Richard Garland Thomas, Jr., Hans W. Treupel, Robert Turner, Roberto Vaglio-Laurin, Alan A. Ware, Ramabhadra Vasudevan, Lee O. Webster, Lawrence W. Weston, Donald Ray Wiff, Colin S. Wiggins, William Walter Willmarth, Friedwart M. R. W. Winterberg, Richard L. Witkover, Andrew Wittkower, Kyral F. Wylie.

Elected to Student Membership as of July, 1960, by the "alternative scheme" authorized in Article IV, Section 1, of the Constitution: Gerald Abowitz, Donald W. Aitken, Jr., Ernest C. Alcaraz, Ralph L. Amey, Ann Bankofier, R. Keith Bardin, Francis A. Bills, Paul Anthony Bonczyk, Chuen-Chuen Chang, Che Jen Chen, Dev Raj Chopra, Mikael Ciftan, Irving E. Collett, John A. Dahlquist, Carl W. David, John Oliver Dimmock, William B. Dixon, Timothy R. Donoghue, Jerry T. Dowell, Guenther E. H. Dulz, Carl E. Edmund, John R. Ehrman, George A. Fairbanks, III, Roger Fernand Favreau, Harvey Jack Fliegelman, William F. Fuller, James T. Fulton, Joseph N. Gayles, Jr., Samuel L. Greene, C. Richard Hagen, Vasken Hagopian, Eldon L. Haines, Roland C. Hanson, Shigeo Hatsukade, James Marbury Hawkins, Jr., Roald Hoffmann, Henry M. Horstman, Jr., Lynn D. Ikenberry, M. Anthony Jensen, Peter C. H. Jordan, Joshua Leon Kanet, Nicholas Karayianis, Charles Andrew Kelsey, Tadashi Kikuchi, Shigern Kounosu, Arthur Z. Kovacs, James D. Lea, Richard Y. Y. Lee, Yung C. Lee, Angela Chi Li, Lawrence L. Lohr, Jr., Kleber S. Masterson, Jr., Thomas H. May, James B. Mead, Marvin V. Mielke, John C. Miklosz, Jr., David C. Miller, Frederick I. Mopsik, Daniel R. Muss, Richard J. Noer, Elizabeth Katherine Osborn, Hugh N. Pendleton, James C. Person, Francis Joseph Petrone, Jr., M. Jane Phillips, Noel Bradford Proctor, John M. Prosser, J. Thomas Ratchford, Arnold David Nudell, Baldwin Robertson, Andres Desiderio Sanchez, Jack T. Sanderson, Harvey Scher, Basil J. Shepstone, Talivaldis I. Smits, Barry F. Stein, Richard Owen Stenerson, Phillip J. Stiles, George S. Stranahan, Theodore F. Stubbs, Barry N. Taylor, Martial Leon Thiebaux, Jr., Johannes C. Vanderleeden, Carl M. Verber, Joseph L. Vogl, Rochus E. Vogt, J. Pierce Webb, Calvit H. Williams, Jr., Thomas G. Williamson, Gene H. Wojciechowski, Frank C. Young, Chris D. Zafiratos, J. David Zook.

Errata Pertaining to Abstracts CA12, FA2, HA13, HA15, I5, JA3, L3, and UA5 of the 1960 Spring Meeting in Washington, D. C.

(Series II, Vol. 5, No. 4)

CA12, by W. O. Doggett and T. E. Todd. In line 19, instead of "$(\epsilon_0\epsilon_1\epsilon_2 Nm)^{\frac{1}{2}}$" read "$(\epsilon_0\epsilon_1\epsilon_2 Nm)^{\frac{1}{3}}$." In line 20, instead of "negligible coincidences" read "negligible accidental coincidences."

FA2, by Monroe Cowan and Walter Gordy. In line 9, in the last bracket of the formula, instead of "$(2J^2+6J+4)$" read "$(3J^2+6J+4)$." In lines 17 and 18 instead of "$B_0=10\,680.45$ Mc/sec" read "$B_0=10\,681.096$ Mc/sec"; instead of "$D_J+0.0095$ Mc/sec" read "$D_J=0.0146$ Mc/sec"; instead of "$D_{JK}=-0.022$ Mc/sec" read "$D_{JK}=-0.0228$ Mc/sec."

HA13, by J. A. Jacobs, A. C. L. Barnard, R. R. Carlson, and C. C. Kim. The last sentence should read "Spin and parity assignments were then made to some F^{19} levels as follows: $E_x=8.763$ Mev $j_\pi=\frac{1}{2}+$, $E_x=9.609$ Mev $j_\pi=\frac{3}{2}-$, $E_x=9.636$ Mev $j_\pi=\frac{3}{2}+$, and $E_x=9.865$ Mev $j_\pi=\frac{1}{2}+$."

HA15, by W. D. Ploughe, E. Bleuler, and D. J. Tendam. In line 19, instead of "$R=7.4f$" read "$R=6.47f$."

I5, by H. E. Wegner and W. S. Hall. In line 2, instead of "Wegener" read "Wegner."

JA3, by L. M. Langer and D. R. Smith. Line 5, instead of

$$"C\sim(W_0-W)^2+10\pm5"$$

read

$$"C\propto(W_0-W)^2+0.845(W^2-1)+10\pm5."$$

L3, by R. C. Haymes and S. A. Korff. In line 12, instead of "also decreased markedly" read "flattened out."

UA5, by Robert E. Warner and John H. Tinlot. In the 4th line from the end of the text, instead of "$+0.364\pm0.043$ for $\theta_{c.m.}=30°$" read "$+0.496\pm0.026\pm0.026$ for $\theta_{c.m.}=50°$."

Minutes of the Second Conference on Reactions between Complex Nuclei, Held in Gatlinburg, Tennessee, May 2–4, 1960

THE Second Conference on Reactions between Complex Nuclei was held in the pleasant surroundings of the Great Smoky Mountains. There were 112 registered participants; 40 papers were presented during the two-and-a-half day meeting. Everyone stayed at the Mountain View Hotel, next to the meeting hall, so that a congenial and informal atmosphere pervaded the meeting. The hotel's heated swimming pool provided just the right kind of relaxation for bodies cramped by conference chairs.

The Conference was organized by R. S. Livingston with the help of A. Zucker and D. D. Cowen, all of the Oak Ridge National Laboratory. Union Carbide Nuclear Company was host at an informal get-together on the evening preceding the Conference.

With this Second Conference on Reactions between Complex Nuclei, there is now established a pattern for possible future biennial reviews of research in nuclear physics accomplished with heavy ions.

R. S. Livingston, *Chairman*

Contributed Papers

A1. Nucleon Transfer Theory.* G. Breit, *Yale University.* The probability of nucleon transfer through the gap between nuclear surfaces at low bombarding energies and/or orbits with small deflection angles depends on nucleonic reduced widths in bound states. Inaccuracies in deriving reduced widths from measured cross sections will be discussed from the following viewpoints. (a) A one-dimensional schematic model allows derivation of exact formulas for transfer probabilities. Comparison of these[1] with the barrier penetration type approximation[2] will be presented, and reasons for paying attention to data at low bombarding energies or small scattering angles will be discussed. (b) Uncertainties caused by virtual Coulomb excitation and methods of partially eliminating them by employing ratios of cross sections for different nuclei. (c) Corrections for quantum effects on the motion of the colliding nuclei. (d) Effect of transfers to real and virtual excited states and resulting complications. (e) Aids to interpretation arising from plots of $\ln(E\sigma)$ against $1/E$ and of $\lambda^{-2}\, d\sigma/dr_{\min}$. (f) Close collisions giving nuclei with transferred nucleons appearing at small angles.

* This work was supported by the U. S. Atomic Energy Commission and by the Office of Ordnance Research, U. S. Army.
[1] In collaboration with Dr. Y. Nishida and Mr. G. Herling.
[2] G. Breit and M. E. Ebel, Phys. Rev. **103**, 679 (1956); **104**, 1030 (1956).

A2. Neutron Transfer and the Tunneling Mechanism.* J. A. McIntyre, F. C. Jobes, and T. L. Watts, *Yale University.*—The neutron transfer reaction $Au^{197}(N^{14}, N^{13})Au^{198}$ has been studied at fifteen different bombarding energies by measuring the angular distributions of the N^{13} nuclei. The angular distributions can be described in terms of the transfer of a neutron from an N^{14} nucleus moving along a classical trajectory. In particular, it is found that N^{14} trajectories with distances of closest approach of $(12.7\pm0.5)\times10^{-13}$ cm give the largest contribution to the transfer process. Range measurements of the N^{13} nuclei show that, as the N^{14} bombarding energy increases above the Coulomb barrier energy, the probability increases for the transferred neutron to go to the continuum of the Au^{197} nucleus, rather than to a bound state. Finally, both the angular and energy dependence of the N^{13} production have been compared with the dependences predicted by the tunneling theory of Breit and Ebel; near the Coulomb barrier energy both experimental dependences have been found to be in agreement with this theory.

* Supported by the U. S. Atomic Energy Commission.

A3. Neutron-Transfer Reactions from Bombardments by 124-Mev C^{12} Ions and 145-Mev N^{14} Ions. Edward L. Hubbard and George Merkel, *Lawrence Radiation Laboratory.*—Several thin metallic targets from Cu to Au have been bombarded with 124-Mev C^{12} ions and 145-Mev N^{14} ions. Angular distributions and energy distributions of the C^{11} reaction products from the C^{12} bombardments and of the N^{13} reaction products from the N^{14} bombardments have been measured by collecting the reaction products in $\frac{1}{4}$- or $\frac{1}{2}$-mil stacked Al foils. Measurements were made in the interval from 5 to 30 deg. Peaks in the angular distributions are observed in the forward direction and in some cases also at larger angles. The energy distributions peak at an energy corresponding to the transfer of a neutron to the continuum of the target nucleus. The angular distributions may be explained by the Breit and Ebel theory of neutron transfer by virtual Coulomb excitation if both $E1$ and $E2$ Coulomb interactions occur.

A4. Multi-Nucleon Transfer and Grazing Reactions of Heavy Ions. R. Kaufmann and R. Wolfgang, *Yale University.*—Nuclear interactions of heavy ions of low energy may be divided into processes in which the incident particle is deflected by the Coulomb potential and those in which it penetrates to form some kind of compound nucleus. At higher energies there should be, however, a range of impact parameters for which, although the Coulomb barrier is penetrated, the nuclear bond that is formed is exceeded by the centripetal and Coulomb forces which again separate the system. The resultant grazing collision should provide a means for the transfer of several nucleons. The production of high-velocity C^{11}, N^{13}, O^{15}, and F^{18} from O^{16} and also from C^{12}, N^{14}, and F^{19} has been studied. The strongly forward peaked angular distributions and the excitation functions of the multi-nucleon transfer products agree well with the grazing or contact transfer model. Single-neutron transfer seems to show angular distributions indicating that it occurs both by contact transfer and the more familiar barrier tunneling. Other possible mechanisms for multi-nucleon transfer appear inconsistent with these data. The excitation function for grazing collisions should rise from a high threshold to approach the geometrical cross section. In view of the observed cross section for transfer it is plausible that breakup of the incident particle is a more usual result of grazing collision.

A5. Angular Distribution of N^{13} from N^{14} on N^{14}. K. S. Toth, *Oak Ridge National Laboratory.**—The angular distribution of N^{13} produced in the reaction $N^{14}(N^{14},N^{13})N^{15}$ has been determined using 26.5-Mev N^{14} ions. Aluminum catcher foils, arranged so that the entire solid angle at a given angle could be detected were used to stop the radioactive N^{13}. Absorber foils were placed in front of the catchers and their thicknesses chosen so that only those N^{13} atoms that left the N^{15} recoils in their ground states could reach the catcher foils. After 20-min

bombardments, the catchers were counted in Geiger counters and the amount of N^{13} present in each foil determined by resolving the appropriate decay curve. The differential cross section was measured as a function of center-of-mass angle for angles ranging from 6 to 60°. The distribution peaked at 28±3°. Since the reaction presumably proceeds by means of a neutron transferring between the two interacting N^{14} nuclei, it was of interest to determine the distance of closest approach, i.e., the distance at which the transfer probability is greatest. Use was made of a classical formula for scattering by an inverse-square repulsive potential,

$$R' = (Z_1 Z_2 e^2/2E)(1+\csc\theta/2),$$

where R' is the distance of interest. $d\sigma/dR'$ [a quantity proportional to $d\sigma/d\Omega(\sin^3\theta/2)$] was then plotted vs R', and the distribution was found to peak at R' equal to $10.56\pm0.50 \times 10^{-13}$ cm. This value of R' corresponds to an "r_0" of $2.19\pm0.10\times10^{-13}$ cm. The two quantities are related by the expression $R'=r_0(A_1^{\frac{1}{3}}+A_2^{\frac{1}{3}})$. The large "$r_0$" indicates that transfers occur while the interacting nuclei are widely separated.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

B1. Coulomb Excitation Produced by Oxygen Ions Accelerated in the Aldermaston Tandem Van de Graaff. B. M. ADAMS, D. ECCLESHALL, AND M. J. L. YATES, *AEA, Aldermaston.*—The Coulomb excitation of some low lying nuclear levels has been studied using oxygen ions with energies up to 39 Mev. From thick target γ-ray yields, values of $B(E2)$ have been obtained for the excited states of Cr^{52} (1.43 Mev, $B=0.060\pm0.015e^2$ barns^2), Fe^{56} (0.845 Mev, $B=0.100\pm0.025e^2$ barns^2), V^{51} (0.320 Mev, $B=0.012\pm0.003e^2$ barns^2; 0.930 Mev, $B=0.008\pm0.004e^2$ barns^2), and Co^{59} (~1.1 Mev, $B=0.007\pm0.003e^2$ barns^2; 1.19 Mev, $B=0.030\pm0.010e^2$ barns^2; 1.450 ±0.015 Mev, $B=0.015\pm0.005e^2$ barns^2). The 4+ levels in Sm^{152} (367±4 kev), Sm^{154} (266±3 kev), and W^{186} (406±4 kev) have been excited, and, from coincidence measurements on the decay γ rays, the ratios of the thick target yields of the 4+ levels to the yields of the 2+ levels have been obtained. These ratios have been compared with those calculated assuming the 4+ levels are excited by double $E2$ Coulomb excitation.[1,2] At all bombarding energies the experimental ratios are from ~10% (in Sm^{152}) to ~40% (in Sm^{154}) lower than the calculated ratios.

[1] K. Alder, A. Bohr, T. Huus, B. Mottelson, and A. Winther, Revs. Modern Phys. **28**, 432 (1956).
[2] J. O. Newton and F. S. Stephens, Phys. Rev. Letters **1**, 63 (1958).

B2. Coulomb Excitation with Ne^{20} Ions. P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—The ORNL 5.5-Mv Van de Graaff has been used to obtain Ne^{20} ions with energies up to 11 Mev. The Coulomb excitation produced by these ions has been studied in a number of nuclei ranging in A from Li^7 to Ir^{193}. Ne^{20} ions in this energy range have the advantage that nuclear reactions other than Coulomb excitation have extremely small cross sections. However, with the presently available ion beam intensities, e.g., 0.2 μa of Ne^{6+}, the Coulomb excitation γ-ray yields are so low that room background counting rates are often troublesome. To alleviate this problem, a lead shield for the scintillation detector has been built which has 4-in. walls and inside dimensions of 48×40×18 in. To obtain information on spins and decay modes of excited states, the 0–90° asymmetry ratios were measured for the 128-kev state in Mn^{55} and the 440-kev state of Na^{23}. Since the Ne^{20} ions produce relatively few K x rays during the slowing down process in the target, they are useful for measuring K-shell conversion coefficients of Coulomb excited states. K-shell conversion coefficients for the 136-kev state in Ta^{181} and the 123-kev state in W^{186} have been measured.

B3. Investigation of the Coulomb Excitation of Nuclei by Means of Multiply Charged Ions. I. KH. LEMBERG, *Leningrad Physical-Technical Institute, Academy of Sciences.*—By means of "heavy" ions as bombarding particles, levels have been excited in the following nuclei: Ne^{20}, Ne^{21}, Ne^{22}, Al^{27}, Mg^{24}, Si^{28}, P^{31}, S^{32}, Sc^{45}, Cr^{50}, Cr^{52}, Cr^{54}, V^{51}, Mn^{55}, Nb^{93}, Pr^{141}, and Nd^{144}. These levels previously could not be observed because of a high background from nuclear reactions when protons or α particles were used. In cases when nuclear levels have been excited previously with α particles (Ni^{58}, Ni^{60}, Ni^{62}, Ni^{64}, Rb^{87}, Sn^{117}, and Sn^{119}) the use of ions heavier than α particles made it possible to confirm the Coulomb origin of the investigated γ rays. The energies of excited levels, the reduced probabilities $B(E2)$, and hence the lifetimes $\tau(E2)$ were determined. It was established that some γ lines observed in bombarding chromium with protons and α particles and manganese with nitrogen ions are not due to Coulomb excitation. The data on excitation of Ne^{20}, Ne^{21}, and Ne^{22} have a peculiarity in being obtained by means of exciting levels in the bombarding particles (the corresponding neon ions) and not in the target nuclei. The double Coulomb excitation of second rotational levels with spins 4^+ in separated wolfram isotopes W^{182}, W^{184}, and W^{186} was observed. The background γ-ray spectrum due to nuclear reactions of ions C^{12}, N^{14}, and O^{16} with carbon and oxygen was investigated.

B4. Coulomb Excitation in Nuclei from $A=23$ to $A=60$ Using O^{16} Ions. H. E. GOVE AND C. BROUDE, *Chalk River Laboratories.*—Values of $B(E2)$ for low-lying levels in a number of nuclei have been measured using the O^{16} ion beam from the Chalk River tandem accelerator. In all cases, for each element the thick target Coulomb excitation yield was measured over a wide range of incident oxygen ion energy, and the results were fitted to theory using the Chalk River Datatron computer with $B(E2)$ as the parameter. The following values were obtained, where $B(E2)$ in units of $e^2\times10^{-48}$ cm^4 in parentheses follows the level energy: Na^{23} 0.435 Mev (0.0095), Mg^{24} 1.368 Mev (0.034), Al^{27} 0.842 Mev (0.0012) 1.013 Mev (0.0021), Si^{28} 1.78 Mev (0.025), V^{51} 0.322 Mev (0.013) 0.931 Mev (0.038), Mn^{55} 0.983 Mev (0.018), and Fe^{56} 0.845 Mev (0.10). Results for Ni^{58} 1.425 Mev and Ni^{60} 1.333 Mev will be presented. Preliminary measurements of the Coulomb excitation of the 0.534-Mev level in Na^{23} also were made using Cl^{35} ions of energy up to 50 Mev. With the exception of the two levels in Al^{27} all the values of $B(E2)$ are enhanced over the single-particle values by factors ranging from 2 to 20. Coincidence measurements between inelastically scattered oxygen ions and gamma rays in the Coulomb excitation process employing junction counters are being investigated to reduce background from nuclear reactions.

B5. On the Theory of Multiple Coulomb Excitation with Heavy Ions. KURT ALDER AND AAGE WINTHER, *ETH, Zurich.*—In many cases the Coulomb excitation with heavy ions cannot be treated in the usual first-order perturbation theory. The excitation probability in a single encounter can be of the order of magnitude one. In such cases multiple Coulomb excitation occurs. The excitation cross sections have been calculated for rotational and vibrational states, where these multiple processes are most important. For other cases general calculation procedures have been developed, and these will be illustrated through examples. For the larger part of the work the collision time is assumed to be short compared to the nuclear period. The investigation is furthermore simplified by an approximate treatment of the dependence of the cross section on deflection angle of the projectile. The accuracy of the approximations also will be discussed.

B6. Coulomb Excitation with Heavy Ions.* B. ELBEK, F. F. STEPHENS, JR., G. IGO, AND R. M. DIAMOND, *Lawrence Radiation Laboratory.*—The O^{16}, Ne^{20}, S^{32}, and A^{40} beams from the

Berkeley HILAC have been used to study Coulomb excitation in the heavier elements. The use of these heavy ions at energies near the barrier enhances the probability of observing higher-lying levels by either multiple or direct excitation over that obtainable by protons or alphas. For example, observation of the $2+ \rightarrow 0+$, $4+ \rightarrow 2+$, $6+ \rightarrow 4+$ rotational transitions in W^{182} indicate triple electric quadrupole excitation of this nucleus by 168-Mev A^{40}. With the more highly deformed U^{238} and Th^{232} nuclei irradiation by 190-Mev A^{40} leads to 6th- and 5th-order excitation to the $12+$ and $10+$ levels of the ground state rotational bands, respectively. Multiple excitation also has been observed with odd-mass nuclei. The (presumably) $15/2+$ and $13/2+$ levels of the ground state rotational band, as well as the already well-known $11/2+$ and $9/2+$ levels, have been excited in Ta^{181} by A^{40}. Higher-lying levels also can be reached by direct excitation with the heavy ions. The complex of transitions from 625 to 790 kev, as well as new transitions of 1 Mev, have been observed in Th^{232}. Similarly, new transitions at 660 kev and 1.0 Mev in U^{238} have been observed in the excitation by 80-Mev O^{16}, and the nature of the parent levels is being studied.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

B7. Disintegration of Li^6 in Collisions with Gold Nuclei.* CARL E. ANDERSON, *Yale University.*—An ion source has been developed to produce an intense beam of Li^6 ions which can be accelerated in the Yale heavy ion accelerator. The first experiment being performed with these ions is the disintegration of the Li^6 nucleus in collisions with gold nuclei. Alpha particles, deuterons, and protons are observed as disintegration products. Angular distributions of the alpha particles have been measured at bombarding energies of 60, 35, and 25 Mev. The total cross sections for the observed alpha particles are approximately 500, 400, and 40 mb. Alpha-particle energy distributions also have been measured at several energies and angles. Preliminary results indicate a maximum in the alpha-particle energy at the same energy per nucleon as that of the incident beam. The full width at half maximum of the energy distribution is about 8 Mev at a bombarding energy of 35 Mev and increases to 14 Mev at a bombarding energy of 60 Mev. These results are inconsistent with the predictions of compound nucleus, evaporation theory. They are more in accord with an interpretation based upon a combination of nuclear stripping and Coulomb excitation of Li^6 to unbound levels with subsequent disintegration.

* Supported by the U. S. Atomic Energy Commission.

B8. Coulomb Disintegration of Li^6 by Heavy Nuclei.* R. L. GLUCKSTERN AND G. BREIT, *Yale University.*—In connection with observations[1] on disintegration of Li^6 in collision with Au, calculations regarding the effect of the electric field of a heavy target causing $\alpha+d$ breakup have been made. Estimates of $E2$ transitions from the ground state $(1+)$ of Li^6 to excited states 2.18 Mev $(3+)$, 4.52 Mev $(2+)$, and 5.5 Mev $(1+)$ have been carried out and angular distributions of alpha particles resulting from the disintegration of these states approximately calculated. For bombarding energies between 30 and 60 Mev the $3+$ level appears to be the more important. Quantitative comparison proved difficult on account of (a) uncertainties regarding wave functions and transition moments, (b) apparent largeness of excitation probabilities suggesting possible importance of cascade excitations and reorientation effects, (c) probable participation of stripping[2] especially at higher bombarding energies. Although it has not proved possible to derive from measurements values of transition moments $B(E2)$, the variation of $\sigma(\alpha)$ with energy and angle suggests that Coulomb disintegration is a major contributor.

* This research was supported by the U. S. Atomic Energy Commission and by the Office of Ordnance Research, U. S. Army.

[1] C. E. Anderson, W. J. Knox, and A. R. Quinton, Bull. Am. Phys. Soc., Ser. II, 5, 292 (1960).
[2] McIntosh, Rawitscher, and Breit (unpublished).

C1. Small-Angle Elastic Scattering of Heavy Nuclei.* J. S. MCINTOSH, S. C. PARK, AND G. RAWITSCHER, *Yale University.*—The study is a continuation of a previous one[1] with emphasis on correlating nucleus-nucleus with nucleon-nucleus interactions. For one nucleus (A) a Woods-Saxon (WS) potential is adjusted to reproduce Hofstadter's charge distribution. The second nucleus (B) is represented either by (1) a shell model potential reproducing the charge distribution or by (2) a nucleon-nucleus WS optical potential with parameters[2] extrapolated to negative energies. Distortion by B of wave functions leaking out of A is taken into account, but the reaction on the interior of A is not considered. The treatment employs the adiabatic approximation. Within the uncertainties of the method there is no definite disagreement with experiment ($N^{14}+N^{14}$, $N^{14}+C^{12}$) although better fits to data have been obtained by arbitrary adjustment of the potential.

* This research was supported by the U. S. Atomic Energy Commission and by the Office of Ordnance Research, U. S. Army.

[1] J. S. McIntosh, S. C. Park, and J. E. Turner, Phys. Rev. 117, 1284 (1960).
[2] F. E. Bjorkland and S. Fernbach, Phys. Rev. 109, 1295 (1958).

C2. Scattering and Reactions Involving Lithium Ion Beams. J. MORRIS BLAIR, *University of Minnesota.*—The elastic scattering of Li^7 by Li^7 was studied using coincidence methods at $\theta_{c.m.}=90°$ over the energy range of 2.8 to 3.6 Mev. Below 3.2 Mev the yield followed Mott scattering, while above that energy there was a linear departure, reaching 90% of the predicted Mott scattering yield at 3.6 Mev. This result corresponds to a 10° S-wave phase shift. In connection with this scattering work the average carried by the Li^7 ions after passing through a thin nickel foil was measured. This varied from 1.9 electron charge units at 1.55 Mev to 2.4 units at 3.6 Mev. The angular distribution of α particles from the $Li^6(Be^9,B^{11})He^4$ reaction has been studied using a proportional counter-scintillation counter analyzer which enabled α-particle pulses to be separated from others present. For 3.25-Mev Li^6 ions the ground-state α-particle yield had maxima in the forward and backward directions, minima at $\theta_{c.m.}=70$ and 140°, and another maximum at 110°. The α-particles leaving the B^{11} in its first excited state had yield maxima in the forward and backward directions and a minimum yield at $\theta_{c.m.}=115°$.

C3. Elastic Scattering of Nitrogen from Light Elements. A. ZUCKER AND M. L. HALBERT, *Oak Ridge National Laboratory.**—Twenty-seven-Mev nitrogen ions have been scattered from several light elements, Be, C, N, Al, and Mg. Three types of analyses were used to interpret the data: the Blair sharp cutoff model, Ford and Wheeler's rainbow scattering model, and the optical model. Successful applications and limitations of these three models will be discussed, as well as the information about the nucleus which may be obtained with each. The sharp cutoff model is successful where departure from Coulomb scattering is not very great; the rainbow scattering model fits the data where the departure from Coulomb scattering is larger ($\sigma/\sigma_c<0.1$); and the optical model, perhaps because of the 5 free parameters, was applied successfully where the semiclassical models failed.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

C4. Heavy Ion Reaction Mechanism Studies: Elastic Scattering Data. D. A. BROMLEY, J. A. KUEHNER, AND E. ALMQVIST, *Chalk River Laboratories.*—Measurements of the

excitation curves and angular distributions for elastic scattering of carbon and oxygen ions from carbon and oxygen, and to a lesser extent from magnesium, aluminum, and silicon, have been carried out in the laboratory energy range from 6 to 36 Mev using Au-Si surface-barrier and Si p-n junction detectors and the heavy ion beams from the Chalk River tandem accelerator. In all cases, for energies below the Coulomb barrier, the experimental data are in accord with the predictions for Coulomb scattering. At energies above the Coulomb barrier, however, the C+C results show strong resonant effects while the O+O results do not; the C+O results show resonant features only at energies considerably above the barrier. At these energies the $\phi_{c.m.}=90°$ differential cross sections for all three reactions converge to ~10 mb/sr. A quasi-molecular model is proposed, to describe these results, in which the effective potential is determined predominantly by neutron interactions in the nuclear surface. It is suggested that the marked difference between the C+C and O+O data may reflect the greater deformability of the carbon nucleus and the fact that in the O+O system nucleon transfer requires a change from the p to d shell.

C5. Inelastic Scattering of N^{14} by C^{12}. M. L. HALBERT AND A. ZUCKER, *Oak Ridge National Laboratory.**—The inelastic scattering of N^{14} ions by carbon was studied at 27 Mev using a silicon surface-barrier detector. Even though the counter is capable of extremely good resolution, the over-all resolution was relatively poor because of nonuniformity of the target, beam-energy spread, multiple scattering, etc. The coincidence method therefore was used to identify desired events and distinguish scattering from various states. The predominant inelastic scattering process is the one which leaves the N^{14} in its ground state and C^{12} in its first excited state (4.43 Mev). The differential cross section for this process, measured between 41 and 132 deg c.m., is almost constant at 0.5 mb/sr. The absence of pronounced structure is in marked contrast with the elastic scattering, measured previously. Scattering to the 2.31-Mev $T=1$ state in N^{14} (with C^{12} in its ground state) was not observed, confirming the conservation rule for isotopic spin. The cross section for this process is <5 μb/sr. Scattering to the second excited state of N^{14} (3.95 Mev) also was not observed. This process was difficult to detect because of the similarity of the scattering angles and energies to those for the 4.43-Mev state. It would have been observed if its cross section were greater than 0.1 mb/sr. Likewise, the 4.95- and 5.10-Mev states in N^{14} were difficult to distinguish from the 4.43-Mev state (and impossible to distinguish from each other). Some evidence for one or both these states was obtained; the cross section is $\lesssim 0.2$ mb/sr.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

C6. Elastic Scattering of Heavy Ions by Gold, Lead, and Bismuth.* D. D. KERLEE, *Seattle Pacific College Institute for Research,* AND H. L. REYNOLDS AND E. GOLDBERG, *Lawrence Radiation Laboratory.*—The angular distributions of heavy ions elastically scattered by Au^{197}, Pb^{206}, Pb^{207}, Pb^{208}, and Bi^{209} have been recorded in photographic emulsions at laboratory angles from 17° to 175°. The targets were studied with C^{13}, N^{14}, O^{16}, and Ne^{20} projectiles from the Berkeley HILAC at laboratory energies of 10.4 Mev per nucleon. In general, elastic measurements were taken only at angles for which the ratio of the cross section to the Coulomb cross section σ/σ_c was greater than 0.1. In one case measurements were extended to regions where upper limits of $\sigma/\sigma_c \leqq 1.4\times10^{-4}$ were found. The cross sections all exhibited a behavior similar to that previously reported for C^{12} on Au^{197}. An oscillation in the cross section occurring at smaller angles than the 20 to 30% rise and sudden drop was observed. Excellent agreement with the semiclasical strong absorption model was obtained. Nuclear interaction distances calculated by fitting the strong absorption calculations are consistent with $r_0=1.46$ fermis where $R=r_0(A_1^{\frac{1}{3}}+A_2^{\frac{1}{3}})$.

* Supported by the U. S. Atomic Energy Commission and the National Science Foundation.

C7. Elastic Scattering of C^{13} Ions from Several Nuclei.* J. ALSTER AND H. E. CONZETT, *Lawrence Radiation Laboratory.*—The angular distribution of 124.5-Mev C^{13} ions elastically scattered by Fe, Ni, Ag^{107}, In, and Ta has been measured. The elastically scattered C^{13} ions were detected in a crystal scintillation counter with a geometrical angular resolution of 0.7° and an energy resolution of 2%. The measured differential cross sections will be shown. Attempts to fit the measured differential cross sections with the Blair sharp cutoff model and modifications thereof will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

C8. Elastic Scattering of Various Nuclei for a Fixed Coulomb Interaction.* J. A. MCINTYRE, S. D. BAKER, AND K. H. WANG, *Yale University.*—For values of $\eta=ZZ'e^2/\hbar v$ considerably larger than unity, the sharp cutoff (Blair) partial-wave analysis of elastic scattering has proved to be a reasonable first approximation. Only two parameters are used in this approximation, η and L', L' being the L value at which the partial waves are cut off. η is a measure of the strength of the Coulomb interaction while L' is a measure of the nuclear radius. Experiments have been performed, keeping η and L' fixed ($\eta=31.8$, $L'=93$), for the elastic scattering of O^{16} on Pb^{208} (both doubly magic nuclei) and for F^{19} on Tb^{159}. The difference which appears between the angular distributions for these two cases cannot then be attributed to either the Coulomb field or to the nuclear radii and so presumably arises because of a difference at the nuclear boundaries. Since the O^{16} and Pb^{208} nuclei both are doubly magic and therefore have boundaries of maximum sharpness while F^{19} and Tb^{159} have boundaries of considerable diffuseness, the magnitude of the difference in scattering for these two cases indicates the maximum effect on the elastic scattering that can be caused by conditions at the nuclear surface.

* Supported by the U. S. Atomic Energy Commission.

C9. Elastic Scattering from Light Gases. E. NEWMAN, P. G. ROLL, AND F. E. STEIGERT, *Yale University.*—The elastic scattering of heavy ions from various light gaseous targets has been investigated. Full energy (10 Mev/amu) beams of oxygen have been scattered from helium, nitrogen, oxygen, and neon. Also, full energy carbon ions have been scattered from nitrogen. Reduced-energy beams of oxygen (approximately 6 and 8 Mev/amu) have been scattered from oxygen. This sequence of full energy beam-target combinations effectively varies the classical parameter $\eta=Z_1Z_2e^2/\hbar v$ from unity to about four. The velocity variation duplicates and extends the upper portion of this range. The data have been taken from about 3° c.m. back to about 20° in intervals of the order of 15 min. In all but one case the elastic peak has been lost into a general reaction background at this upper limit. Angular resolutions from 18 min (laboratory) full width at half maximum to 36 min were used. Energy resolution is of the order of 2%. In most cases this is sufficient for clear separation of the elastic group from particles scattering from any known low-lying states. Relative cross sections were taken with respect to a particle monitor and are assigned to probable error of 2%. Absolute values taken by normalization to a faraday are believed to be of the order of 15% or better. Nowhere, in either magnitude or shape, were Rutherford cross sections even approached.

D1. Recent Research with the Heaviest Elements.* ALBERT GHIORSO, *Lawrence Radiation Laboratory.*—Bombardments of

californium with various heavy ions are being conducted in a search for elements with atomic number greater than 102. The methods and results obtained will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

D2. Fission Studies with Carbon and Oxygen Beams.* H. C. BRITT AND A. R. QUINTON, *Yale University.*—Angular distributions and energy spectra of fission fragments have been measured for the reactions (a) $Au^{197}+O^{16}$ at 168 Mev, (b) $Au^{197}+C^{12}$ at 126 Mev, (c) $Bi^{209}+O^{16}$ at 168 Mev, and (d) $Bi^{209}+C^{12}$ at energies ranging from 72 to 126 Mev. All angular distributions can be fitted satisfactorily by curves of the form predicted by Halpern and Strutinski.[1] The most probable fragment kinetic energies in the center-of-mass system are 75 ± 3, 75 ± 3, 81 ± 3, and 81 ± 3 Mev, respectively. The results for the reaction $Bi^{209}+C^{12}$ show that the kinetic energy release is independent of the excitation energy of the compound system. From the angular distributions relative cross sections have been determined.

* This work was supported by the U. S. Atomic Energy Commission.
[1] I. Halpern and V. M. Strutinski, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, p. 398.

D3. Heavy-Ion-Induced Nuclear Fission. A. E. LARSH, G. E. GORDON, T. SIKKELAND, AND J. R. WALTON, *Lawrence Radiation Laboratory.*—The angular distributions, kinetic energy release, and cross sections for fission of gold by carbon ions of various energies have been determined. The kinetic energy spectra of fragments were observed at various angles to the beam in two types of detectors, gas scintillation chambers, and diffused silicon p-n junctions. The center-of-mass fragment angular distributions were fitted to the theoretical curves of Halpern and Strutinski to obtain the values of the parameter $p(=I_m^2/4K_0^2)$.[1] By use of the resulting p values and calculated estimates of the height of the fission barriers, we obtain values for the average excitation energy at which fission occurs. This quantity is quite low and approximately independent of bombarding energy, varying from $\sim$22 Mev with 123-Mev C^{12} to $\sim$20 Mev with 72-Mev C^{12} ions. Apparently, at the higher energies, several particles are emitted prior to fission. The total fission cross section varies from 1.28 barn at 124 Mev to 100 mb at 68 Mev. The most probable total kinetic energy release is 146 ± 6 Mev for the 123-Mev case and is only slightly dependent on bombarding energy. Work is in progress on similar experiments with $U^{238}+C^{12}$.

[1] I. Halpern and V. M. Strutinski, *Proceedings of the Second United Nations International Conference on the Peaceful Uses Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, p. 408.

D4. Intermediate-Energy Fission of Nuclei in the Radium Region Produced by Heavy-Ion Bombardment.* K. M. CLARKE, *Yale University.*—Range and angular distribution measurements of recoiling fission fragments from the reactions Pb^{208} (C^{12},f) and Bi^{209} (C^{12},f) were obtained for C^{12} bombarding energies near the Coulomb barrier. The fission fragments were detected with Ilford photographic emulsions placed at various angles with respect to the beam direction. For a maximum excitation energy of about 28 Mev, the range distributions are symmetric, indicating the predominance of symmetric fission. This result is in accord with earlier measurements[1,2] on fissioning nuclei of comparable Z, A, and excitation energy. The range data are interpreted in terms of possible mechanisms for the fission of neutron-deficient nuclei in the radium region having appreciable amounts of angular momentum.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] Fairhall, Jensen, and Neuzel, *Proceedings of the Second United Nations Conference on the Peaceful Uses Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, p. 452.
[2] R. L. Wolke, Bull. Am. Phys. Soc. Ser. II 4, 414 (1959).

D5. Fission of Gold with Carbon Ions.* V. E. VIOLA AND H. M. BLANN, *University of California,* AND T. D. THOMAS, *University of California and Brookhaven National Laboratory.*—The mass distribution of fission fragments from fission induced in gold by 112-Mev carbon ions has been found to peak at mass number 98 and to have a full width at half maximum of 25 mass units. The most probable Z for a given A is predicted better by the hypothesis of constant neutron-to-proton ratio (equivalent to that of Bi^{198}) than by the hypothesis of equal displacement from the line of beta stability. The angular distribution of fission fragments has been measured for carbon-ion energies of 125, 107, and 92 Mev. The ratio of differential cross section at 0° (c.m.) to that at 90° is 4.8 at 125 Mev, 4.2 at 107 Mev, and 3.8 at 92 Mev. The kinetic energy of fission is 138 Mev, independent of the bombarding energy. Interpretation of the results in terms of the theories of Griffin and of Halpern and Strutinski indicate that, in the highest energy bombardment, 6 to 8 neutrons are emitted before fission. Results of some calculations on the effect of angular momentum on the competition between fission and neutron evaporation will be presented.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

D6. Fission of Gold, Lead, and Bismuth by Heavy Ions.* E. GOLDBERG AND H. L. REYNOLDS, *Lawrence Radiation Laboratory,* AND D. D. KERLEE, *Seattle Pacific College Institute for Research.*—Fission fragment angular distributions for the reactions $C^{12}+Au^{197}$, $N^{14}+Bi^{209}$, $Ne^{20}+Bi^{209}$, $C^{12}+Pb^{208}$, $N^{14}+Pb^{208}$, $O^{16}+Pb^{208}$, and $Ne^{20}+Pb^{208}$ have been determined experimentally at laboratory angles from 17° to 175° and at laboratory energies of 10.4 Mev per nucleon. The elastically scattered particles which were recorded simultaneously by the photographic emulsions permitted a determination of the absolute fission cross sections. The fission fragment range spectra were measured at 10-deg intervals. Fragment energies are consistent with fore-and-aft symmetry in the center-of-mass system. Also, the variation of fragment energy with angle is consistent with the symmetry condition. To illustrate, the $C^{12}+Au^{197}$ reaction is found to yield a total fission cross section of 1.7×10^{-24} cm^2. The elastic data indicates a total reaction cross section of 2.11×10^{-24} cm^2. The range data yield a transformation parameter of approximately $0.23(=V_{eq}/V_0)$, assuming symmetric fission. Agreement with the relative fission angular distribution of Gordon *et al.*[1] is satisfactory.

* Supported by the U. S. Atomic Energy Commission and National Science Foundation.
[1] G. E. Gordon, A. E. Larsh, and T. Sikkeland, UCRL-9003, and Phys. Rev. Letters (to be published).

D7. Radioactivities Induced by Lithium Ions. EDWIN NORBECK, *University of Minnesota.*—Selected reactions of Li^6 and Li^7 beams with targets in the range $Z=3$ to $Z=11$ have been studied by measuring radioactive reaction products. The bombarding energies ran from 1.1 to 4.0 Mev. The techniques used allowed measurement of yields as low as one atom per 10 μcoul of beam. All of the measured thick target yields were rapidly increasing functions of energy. The yield of $Li^7(Li^6,2n)C^{11}$, from a thick Li^7F target, increased by a factor of 3×10^4 between 1.2 and 3.6 Mev. The maximum nuclear cross section measured was 70 mb for $Be^9(Li^7,Li^8)Be^8$ at 4.0 Mev. The angular distribution of the Li^8 from this reaction shows a single peak (laboratory system) which shifts forward from 59° at 1.71 Mev to 28° at 4.0 Mev. At 1.71 Mev the classical distance of closest approach is 18.0×10^{-13} cm. This angular distribution cannot be explained, therefore, by any theory which calls for contact between nuclear surfaces.

D8. Experiments at Saclay with 2-Mev Lithium Ions. S. M. SHAFROTH, *Northwestern University and Saclay.*—To study nuclear reaction mechanisms with lithium nuclei as projectiles

the Saclay 2-Mev Van de Graaff has been converted to a lithium accelerator, and a multiangle nuclear emulsion plate camera has been used to measure angular distributions of the charged particle reaction products. The main work so far has involved Li^6+C^{13}. Proton groups leading to the ground state (p_0), the 1st, 2nd, and 4th excited states (p_1,p_2,p_4) of O^{17} have been observed. A group which could be protons to the third excited state of O^{17} (p_3) or deuterons to the ground state of O^{18} (d_0) also has been observed. Preliminary measurements have been made of the angular distributions for groups p_2, p_3 or d_0, and p_4. Group p_2 shows a strong rise in the forward direction. The group p_3 or d_0 exhibits a smaller rise in the forward direction, and group p_4 appears to be symmetric with respect to 90° c.m. Total cross sections have been obtained for these three groups. Differential cross sections at certain angles have been obtained for all five groups. The first four proton groups from Li^7+C^{13} have been identified, and differential cross sections are measured. Ground-state alphas arising from the bombardment of C^{13} by Li^6 and Li^7 have been observed.

D9. Nuclear Reaction Products from the Lithium Bombardment of Li^7 and Li^6 Targets.* G. C. MORRISON AND M. N. HUBERMAN, *Enrico Fermi Institute for Nuclear Studies.*—Angular distributions of the emergent protons, deuterons, and tritons from the lithium-induced reactions in Li^6 and Li^7 targets leading to discrete states in the final nuclei are being studied for an incident lithium energy of 2.1 Mev. Identification of the outgoing particles is achieved with a proportional counter—CsI (Tl) scintillation counter telescope system which gives a measure of the "dE/dx" and E of the emitted particles. In the reaction $Li^7(Li^6,d)B^{11}$ angular distributions have been obtained for the deuterons leading to the ground state and first few excited states of B^{11}. Deuterons leading to the ground and third excited states show a forward peaking, whereas those leading to the first and second excited states have a comparatively flat distribution. In the reaction $Li^7(Li^7,t)B^{11}$, however, tritons leading to the ground state of B^{11} show a comparatively flat distribution. Further measurements on the angular distributions of the deuteron and triton groups from the above reactions and also the proton groups from the reaction $Li^6(Li^6,p)B^{11}$ are in progress. Results also will be presented on the angular distributions of emergent particles leading to discrete states in the residual nuclei B^{10}, B^{12}, and B^{13}.

* This research supported in part by a grant from the U. S. Atomic Energy Commission.

E1. Light Particles from Nitrogen-Induced Reactions. C. E. HUNTING, *Oak Ridge National Laboratory.**—Alpha-particle spectra from reactions induced in F^{19} targets by 27.5-Mev N^{14} ions were observed at c.m. angles from about 25° to 95°. Each energy spectrum was fitted with the predictions of a simple exponential energy level density,[1] $\exp(E^*/T)$, where E^* is the excitation energy in the residual nucleus, T is a constant at a given angle, and the assumed reaction is $F^{19}(N^{14},\alpha)Si^{29}$. The fit in each case extended over a range of at least 14 Mev in E^* and was better than a fit using $E^{*\frac{1}{2}}$ in the exponential of the level density expression. The resulting values of the nuclear temperature T decreased from about 3.0 Mev to about 2.3 Mev as the angle of observation was increased. This can be compared with alpha-particle spectra from N^{14} bombardment of oxygen,[2] where T decreases from about 2.4 Mev to about 2.2 Mev in the angular range 0° to 75° c.m. Preliminary results on the angular distribution of alpha particles from nitrogen bombardment of F^{19} show a marked anisotropy in the observed angular range, the differential cross section decreasing less rapidly with increase in angle as the excitation energy in the residual nucleus is increased. Alpha particles from N^{14} bombardment of oxygen showed a similar angular distribution. Proton spectra from nitrogen bombardment of F^{19} are now being studied.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] T. Ericson, Nuclear Phys. 11, 481 (1959).
[2] M. L. Halbert and A. Zucker, Phys. Rev. 114, 132 (1959).

E2. Light Particles Emitted in High-Energy Reactions between Complex Nuclei.* WILLIAM J. KNOX, *Yale University.*—Angular and energy distributions of alpha particles, protons, and neutrons emitted in the bombardment of Ni and Au targets with 160-Mev oxygen ions have been measured. The energy distributions of alphas and protons from the O on Ni reaction have the shapes of nuclear evaporation spectra, but the experimental spectra are displaced by several Mev toward lower energies relative to calculated spectra. The angular distributions of the alpha particles and protons in the Ni reaction are approximately symmetric about 90° in the center-of-mass system and are peaked in the forward and backward directions. The distributions can be fit by a function with a single adjustable parameter which is related to the variation of level density with angular momentum and the incoming and outgoing angular momenta. The high-energy neutron angular distributions are similar to the proton distributions. The center-of-mass energy spectra of the alphas in the O on Au reaction peak a few Mev below the classical Coulomb barrier energy as in the O on Ni reaction. However, the center-of-mass angular distributions are strongly peaked at forward angles. The reaction mechanism is not known.

* This work has been supported by the U. S. Atomic Energy Commission.

E3. Recoil Studies of Heavy-Ion-Induced Nuclear Reactions.* J. M. ALEXANDER AND L. WINSBERG, *Lawrence Radiation Laboratory.*—The recoil properties of Tb^{149}, At, and Po from nuclear reactions were investigated. We compare the measured recoil ranges R_{exp} with the values R_{CN} expected for compound nucleus formation. These results and the range-straggling data provide evidence about the reaction mechanism.

Projectile (HI)	Possible reaction	$E_{bombardment}$ (Mev/nucleon)	R_{exp}/R_{CN}
C^{12}, N^{14}, O^{16}, O^{18}	(HI,xn) Tb^{149}	~6	a
C^{12}	(HI,xn) Tb^{149}	6.8	0.9
N^{14}	(HI,xn) Tb^{149}	7.3–8.9	0.4–0.2
Ne^{20}	(HI,pxn) Tb^{149}	8.1–9.9	1.0[b]
Ne^{22}	(HI,pxn) Tb^{149}	7.6–10.2	a
O^{16}	(HI,$2pxn$) Tb^{149}	7.1	0.3
O^{16}	(HI,$2pxn$) Tb^{149}	8.5–9.1	1.0
C^{12}, O^{18}, Ne^{22}	(HI,xn) At, (HI,pxn) Po	~8	c, d
O^{16}	(HI,$2pxn$) At, (HI,$3pxn$) Po	5.0–9.9	1.0–0.8[d]
C^{12}, O^{18}	Bi → At^{211}	~4.7	1.0, 0.8
C^{12}, O^{16}	Bi → At^{211}	~5.3	1.4, 1.8
C^{12}, Ne^{22}	Bi → At^{211}	~5.7	1.0
C^{12}, N^{14}, O^{16}, Ne^{20}	Bi → At + Po	~8	1.0–0.2[d]

[a] Taken to be 1.0 for constructing range-energy curve of Tb^{149} in Al.
[b] Shorter-range component also present.
[c] Taken to be 1.0 for constructing range-energy curve of At (and Po) in Al and Au.
[d] Several components present in decay curves.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

E4. Nuclear Reactions of High-Energy C^{12}, N^{14}, and O^{16} with Carbon. MURRY A. TAMERS AND RICHARD WOLFGANG, *Yale University.*—The reactions of 160-Mev O^{16}, 140-Mev N^{14}, and 120-Mev C^{12} and C^{13} to yield radioactive products have been studied and the results compared with those for proton-induced reactions giving formally similar compound systems. Excitation functions for products formed at lower energies are similar in the corresponding proton and heavy ion cases, indicating that their formation involved similar low-energy,

low-spin compound nuclei. However, no "tail" due to knock-on cascade processes was observed with heavy ions. Yields for higher energy products, chiefly F^{18}, were much higher in the heavy ion bombardments. This may be attributed partly to higher average energy deposition with heavy ions resulting from the absence of knock-on processes, and partly to enhanced alpha emission from the distorted high-spin compound nuclei formed by heavy ions. The contribution of various stripping processes to these yields is discussed.

E5. Carbon Ion Reactions of Tantalum.* A. M. FRIEDMAN AND D. HENDERSON, *Argonne National Laboratory.*—A set of stacked tantalum foils were bombarded in the carbon beam of the Yale heavy ion accelerator. The resulting products were identified by decay characteristics and chemical separations. The compound nuclear reaction and stripping reaction cross sections were studied in the range of 40 to 116 Mev. The (C,xn) cross sections were compared to those calculated by the Jackson model,[1] assuming a varying nuclear temperature.

* Based on work performed under auspices of the U. S. Atomic Energy Commission.

[1] J. D. Jackson, Can. J. Phys. **34**, 767 (1956).

E6. Heavy-Ion-Reaction Mechanism Studies: Reaction Excitation Curves. E. ALMQVIST, D. A. BROMLEY, AND J. A. KUEHNER, *Chalk River Laboratories.*—Excitation curves for α particles, protons, neutrons, and gamma radiation from a number of light elements bombarded by C^{12} and O^{16} ions have been measured in the laboratory energy range 6–35 Mev using thin targets and beams of precisely defined energy from the Chalk River tandem accelerator. In the C^{12} on C reaction resonances ~100 kev wide appear just below the Coulomb barrier, with less prominent structure at higher energies, where the corresponding elastic scattering shows pronounced resonances. Other cases studied, including O^{16} on oxygen, show yield curves rising smoothly in the manner expected for the simple barrier penetration. It is suggested that below the Coulomb barrier two carbon nuclei may form quasi-molecular states with a lifetime $\sim 10^{-20}$ sec terminated by collapse into a compound state that de-excites by particle emission. The lack of such states in O^{16} reactions may reflect the greater rigidity of the closed shell.

E7. "Molecule" Formed by Two Carbon Nuclei. E. VOGT AND H. MCMANUS, *Chalk River Laboratories.*—We discuss the physical origin of the "molecular" system, consisting of two C^{12} nuclei, of the kind required to fit the resonance structure recently observed by Almqvist, Bromley, and Kuehner[1] in all reactions from, and in the elastic scattering of, $C^{12}+C^{12}$. The large formation widths ($\Gamma_{C^{12}}$~100 kev, the sum rule limit) and the large spacing (~300 kev) of the levels precludes a compound nucleus explanation. A model is proposed in which the surface oscillations of the C^{12} nuclei are coupled to the nuclear attraction of their touching surfaces. The resulting motion is a "breathing" of the system (at constant density) along the axis joining the two nuclei, in which the attraction between the touching nuclear surfaces prevents the nuclei from snapping apart. The centrifugal barrier and the Pauli principle inhibit them from coalescing. A deformability of C^{12}, based on its level structure, yields a motion in the breathing mode extending to large distances, reminiscent of fission. The levels in the mode have properties similar to those observed in the $C^{12}+C^{12}$ data. The rigidity of O^{16} may account for the lack of structure in the $O^{16}+O^{16}$ data.

[1] E. Almqvist, D. A. Bromley, and J. A. Kuehner, Phys. Rev. Letters **4**, 515 (1960).

MINUTES OF THE 1960 SUMMER MEETING IN THE EAST HELD AT MCGILL UNIVERSITY, MONTREAL, CANADA, JUNE 15, 16, AND 17

THE 1960 Summer Meeting in the East was not the small, intimate, leisurely affair June meetings usually are. There were 651 registered delegates, 264 contributed papers, and 28 invited papers. The number of registrants and contributed papers was more than double that of the largest previous Summer Meeting in the East. This explosion in size was due to the fact that the Division of Fluid Dynamics and the Division of Plasma Physics met with the Society in addition to the Division of Electron Physics. The Chairman of the Local Committee, Professor E. J. Stansbury of the Department of Physics of McGill University, did an excellent job of arranging everything for the Society. Once the meeting had started, it ran very smoothly, although difficulty with hotel reservations was experienced by some of the members. The meeting was, unfortunately, held at a crowded time of the year for Montreal, and the hotels were quite full. However, there was no undue crowding in the sessions, since the new auditoriums at McGill University were available. The weather was not particularly favorable. Two days were sunny and humid, and it rained on the day scheduled for the Garden Party, which had to be moved to the lobby of the lounge of the McConnell Engineering Building.

Several members of the Society commented very favorably on the extension of Faculty Club privileges to APS members attending the meeting. Approximately 150 members of the Society took advantage of this opportunity.

The banquet of the Society was held Thursday evening, June 16, at the Sheraton-Mt. Royal Hotel, with the President, Victor F. Weisskopf, presiding. The after-dinner speaker was J. S. Foster who gave a charming and amusing talk, reminiscing about the old times at Montreal. The 259 people who were present placed this in the ranks of the better-attended banquets.

We owe a debt of gratitude to Mrs. G. A. Woonton and her assistants, Mesdames R. E. Bell, J. D. Foster, P. A. Lorrain, J. S. Marshall, and E. R. Pounder, who arranged the entertainment for the ladies. Of the 52 women who registered for the meeting, about 30 took part in the various tours

that were arranged. Probably others wanted to go but felt obliged to attend the scientific sessions.

The meeting was enjoyed by those who attended it, and we hope that another joint meeting with our brother physicists in Canada will be held in the not too distant future.

W. W. HAVENS, JR.
Deputy Secretary

Errata Pertaining to Abstracts L4, L10, and V13 of the 1960 Montreal Meeting

(Series II, Vol. 5, No. 5)

L4 by S. J. Pickert. In the title, instead of "$FeCo_3$" read "$FeCO_3$." In the last sentence, instead of "a g factor of 2.5 ± 0.15" read "a g factor of 2.6 ± 0.15."

L10 by Eugenie V. Mielczarek, R. Meister, P. Meijer, J. Jalickee, and D. Shelley. In the next to the last line, instead of "we calculate the fermi momentum in the 100 direction to be 0.721×10^{-19} g cm," read "we calculate the fermi momentum in the 110 direction to be 1×10^{-19} g cm/sec."

V13 by Bernard Goldstein. In line 11, instead of "for both and D_0 is 3×10^7 cm²/sec and 1×10^7 cm²/sec for" read "for both and D_0 is 3.7×10^3 cm²/sec and 2.8×10^3 cm²/sec for."

MEETINGS AND DEADLINES THROUGH AUTUMN 1961

Place	*Meeting dates*	*Deadline date*
Berkeley*	December 29–31	Past
New York	February 1–4, 1961	November 11
Monterey*	March 20–23	January 13
Washington	April 24–27	February 10
Mexico City	June 22–24	undecided
Chicago	November 24–25	undecided
Los Angeles*	December 27–29	undecided
New York	January 24–27, 1962	undecided

Abstracts for the meetings marked with asterisks are to be sent to Professor E. L. Hahn, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for the other meetings listed above are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 p.m. *Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west.* Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected. No abstract postmarked (at the point of dispatch) on deadline day ever reaches the office on time, nor does any abstract postmarked at any point west of the Rockies on the day before deadline day. Some abstracts arrive with covering letters dated three or more days before the postmark; it may be a good idea for you to put your abstract into a United States mail box with your own hands. *The privilege of contributing papers to meetings of The American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

DIVISIONAL MEETINGS AND TOPICAL CONFERENCES (see pages 438 and 439)

Baltimore	Fluid Dynamics	November 21–23	Past
Berkeley	Strong Interactions	December 27–29	Past
Monterey	High-Polymer Physics	March 21–23	January 6

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words or to its actual length in words, whichever is the greater; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original,* the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the ***Bulletin*** are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.*

(*c*) *The Secretary and his deputies have been empowered by the Council to count a footnote either as ten words or as its actual length in words, whichever is the greater length.*

(*d*) *In general, all instructions about an abstract should be typed at the bottom of the page that has the abstract on it,* never *in a covering letter. Covering letters get separated from abstracts!*

(*e*) *Always write your name the same way. Do not use initials in one abstract and then spell it out in another. This complicates indexing. It is preferable to give your name in full.*

The American Physical Society

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Please cut along this line

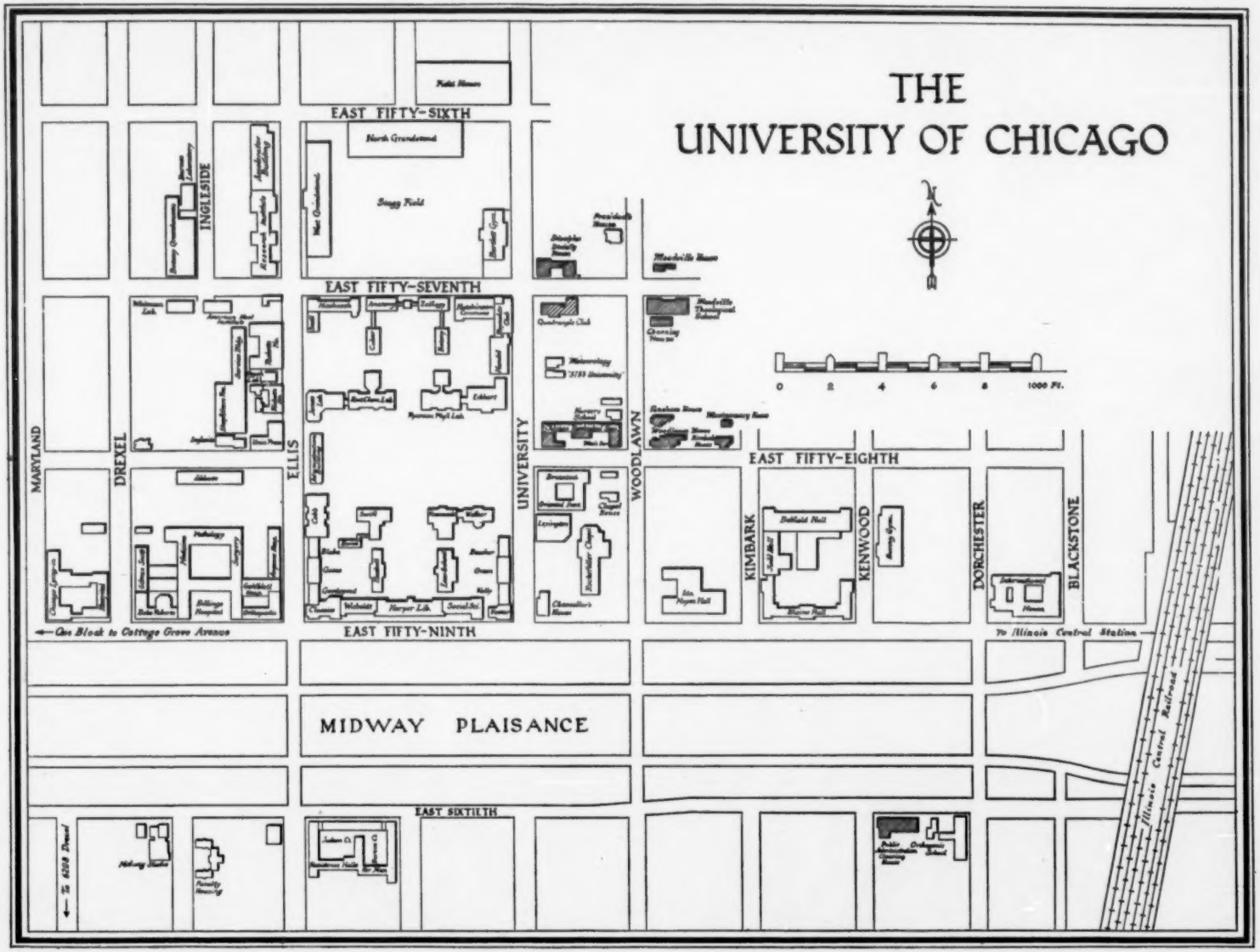
(To be mailed to Frank R. Borchert, Enrico Fermi Institute for Nuclear Studies, 5630 Ellis Avenue, Chicago 37, Illinois)

I EXPECT to attend the banquet of the American Physical Society on the evening of Friday, November 25. My party will consist of ..... persons.

(*Name*).....

(*Address*).....

(If you send a check for $4.50 per person, made out to American Physical Society and it arrives by November 22, you will be assured of tickets and they will be held for you at the registration desk.)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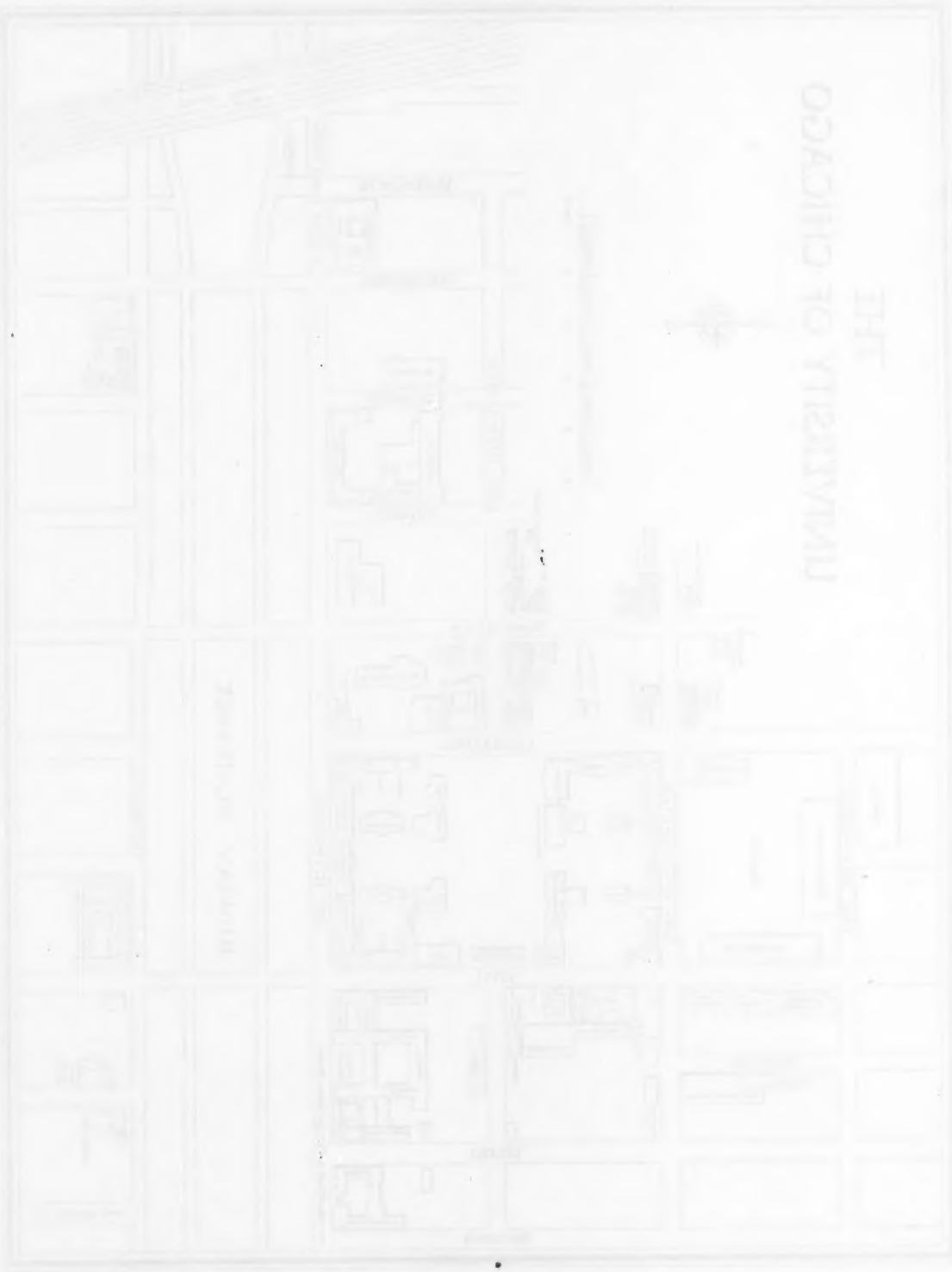
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